High Resolution Coupled Model Activities at GFDL

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Key Questions

- What intra-seasonal - decadal predictability exists in the climate system, and what are the mechanisms responsible for that predictability?

- To what degree is the identified predictability (and associated climatic impacts) dependent on model formulation?

- Is the identified predictability of societal relevance?

Weather <--> Climate Connections

- Several major time scales of variability are often superposed and strongly interacting with each other
- Intraseasonal time scales interact strongly with interannual variability
- Interannual variability is affected by interactions with longer time scales

OUTLINE

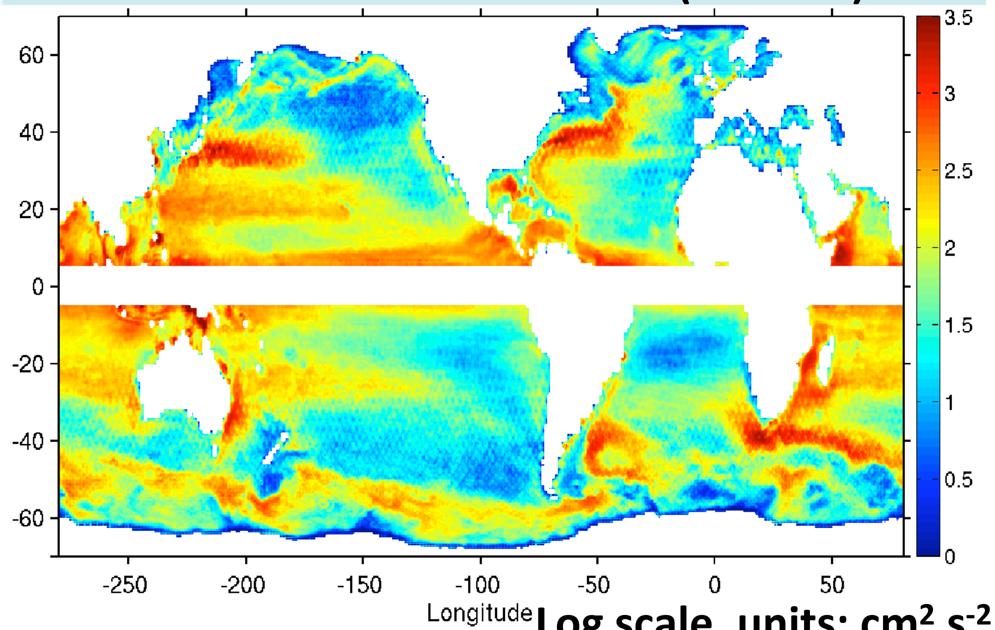
- High Resolution Coupled Model Activities
- Intra-Seasonal
- Interannual
- Decadal
- Remarks

High Resolution Model development

- **Scientific Goals:**
- **Simulated variability and predictability is likely a function of the model**
- **Developing improved models (higher resolution, improved physics, reduced bias) is crucial for studies of variability and predictability**
- **Explore ocean's role in climate variability and change using a high resolution coupled model.**
- **New global coupled models: CM2.4, CM2.5, CM2.6**

	Ocean	Atmos	Computer	Status
CM2.1	100 Km	250 Km	GFDL	Running
CM2.3	100 Km	100 Km	GFDL	Running
CM2.4	10-25 Km	100 Km	GFDL	Running
CM2.5	10-25 Km	50 Km	DOE	Running
CM2.6	4-10 Km	25 Km	DOE	In development

Observational estimates (satellite)



Log scale, units: cm^2 s^{-2}

Eddy Kinetic Energy from satellite records and models (using 5 day means)

Courtesy Riccardo Farneti

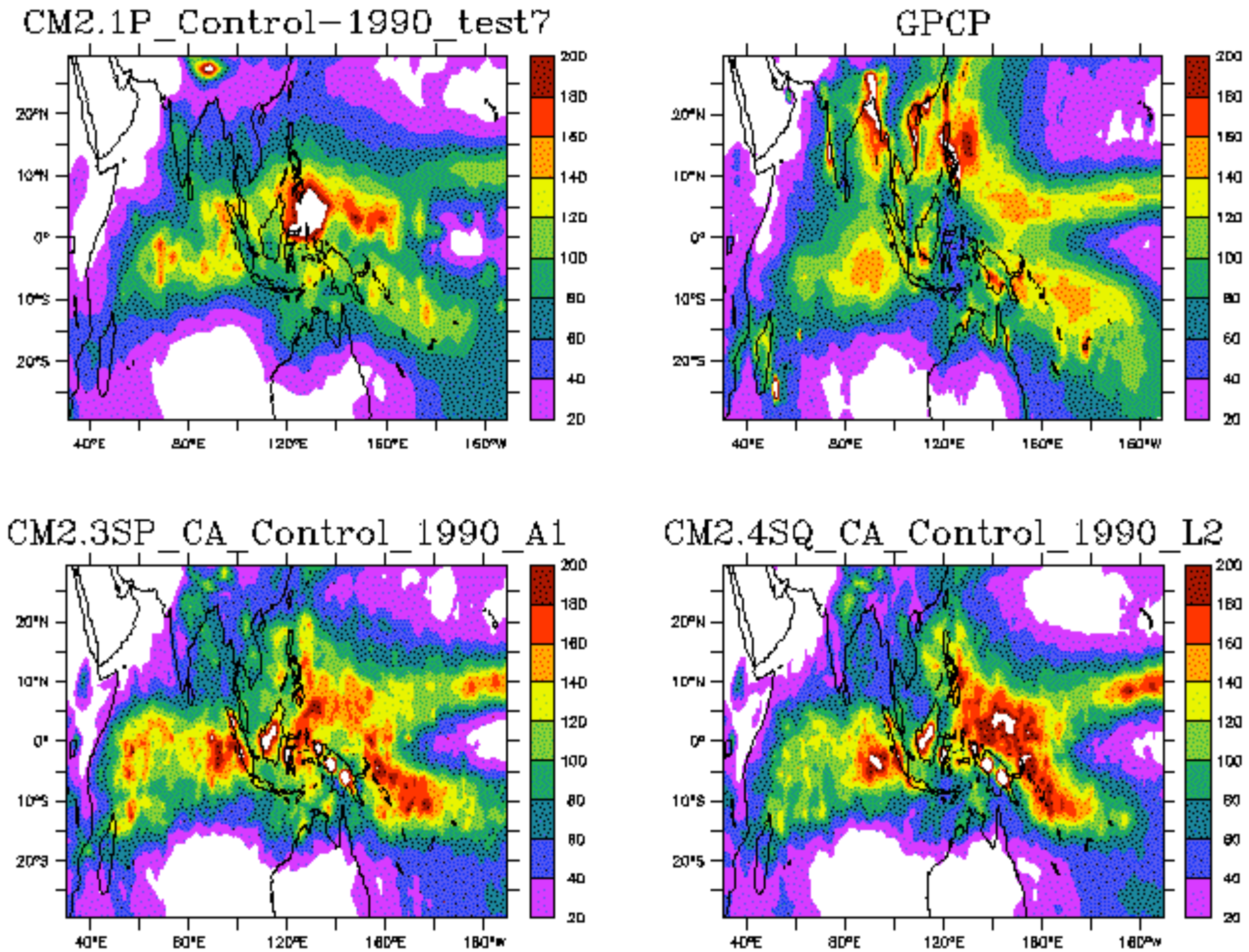
Intra-Seasonal

High Res Climate Modeling: MJO/ISO

Total daily variance vs. ISO daily variance

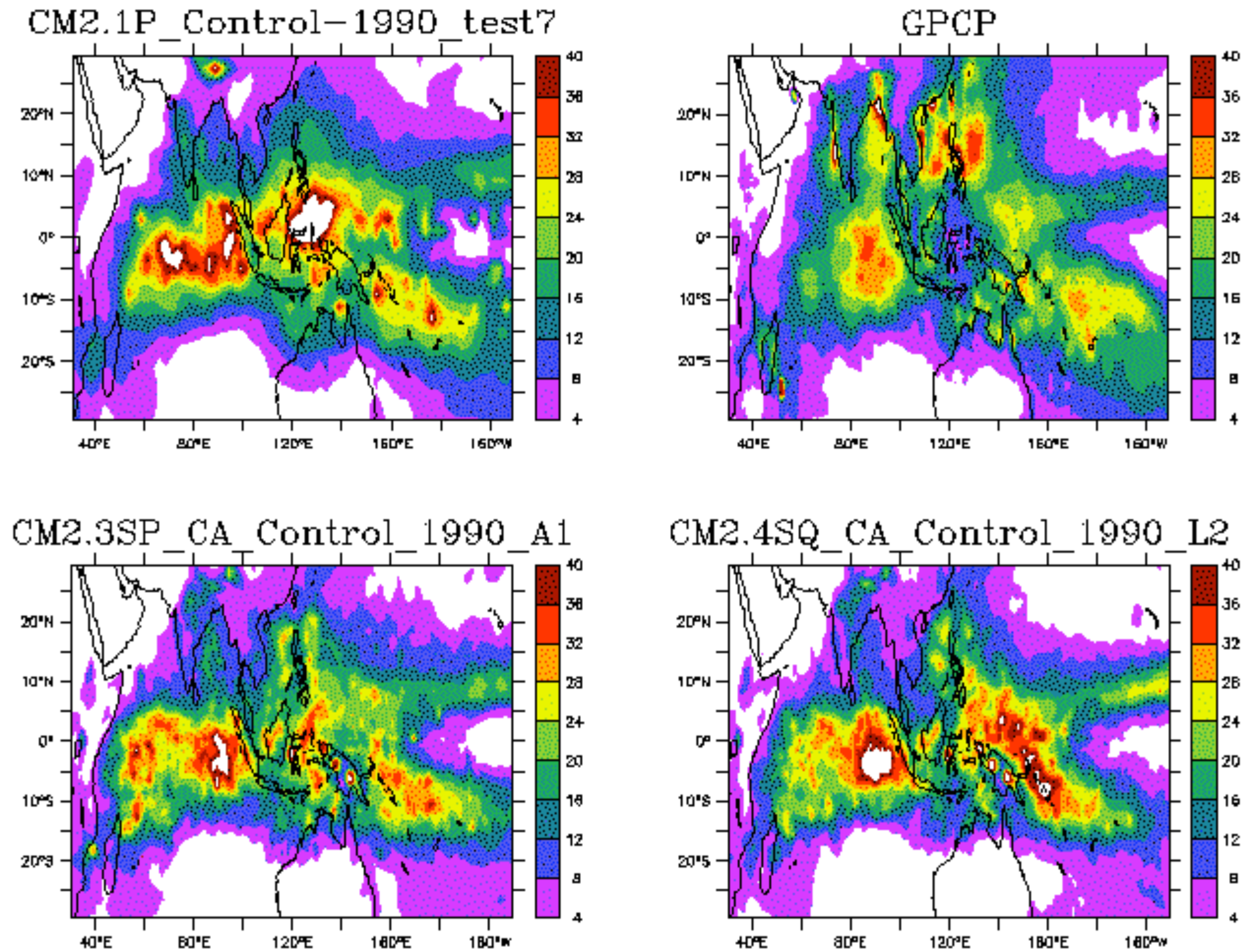
Wheeler Kiladis wave – freq analyses

variance precip_anom (unfiltered,JAN–DEC)



Units = (mm/da)^2

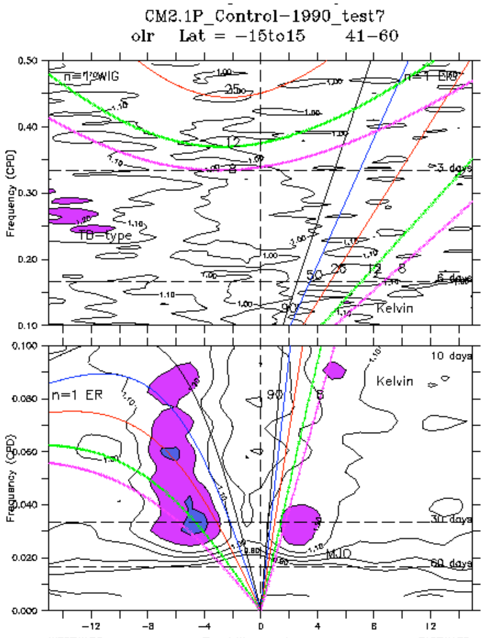
variance precip_anom_fil (20−100da,JAN−DEC)



Units = (mm/da)^2

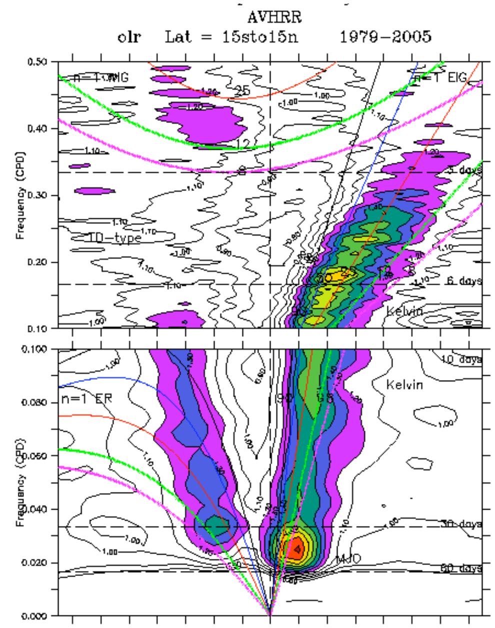
OLR Sym Modes

CM2.1
2deg x 1 deg



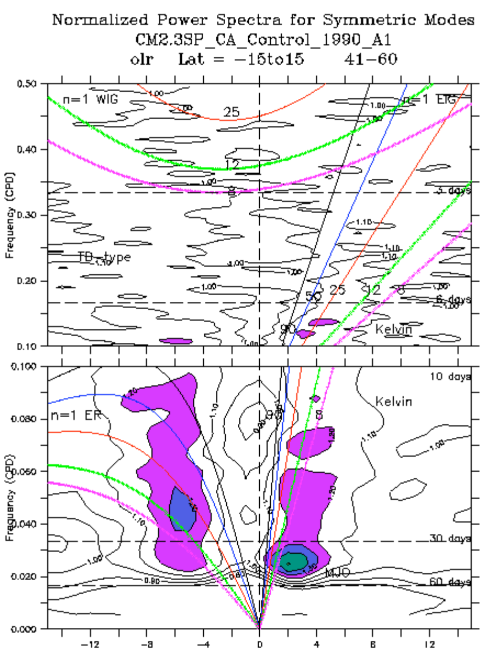
10
30
60

Obs



10
30
60

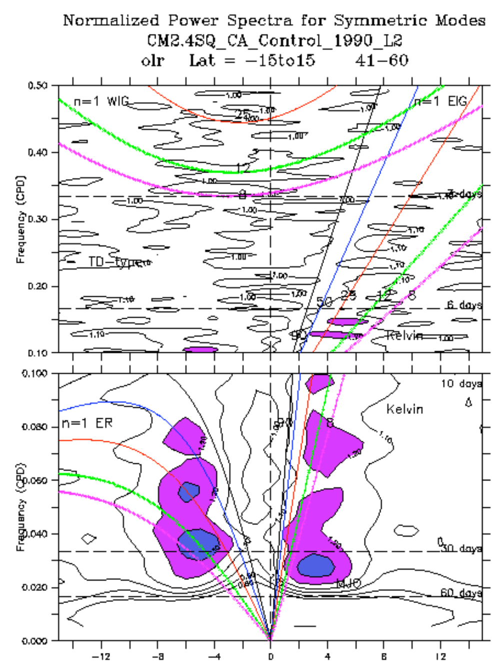
CM2.3
1deg x 1 deg



10
30
60

W Zonal Wave No. E

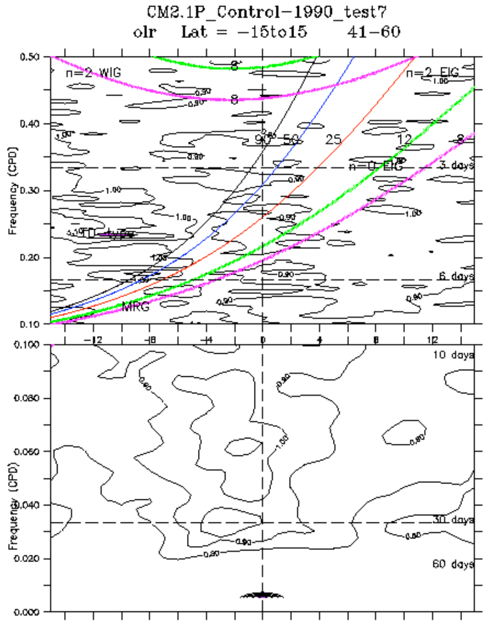
CM2.4
1deg x .25 deg



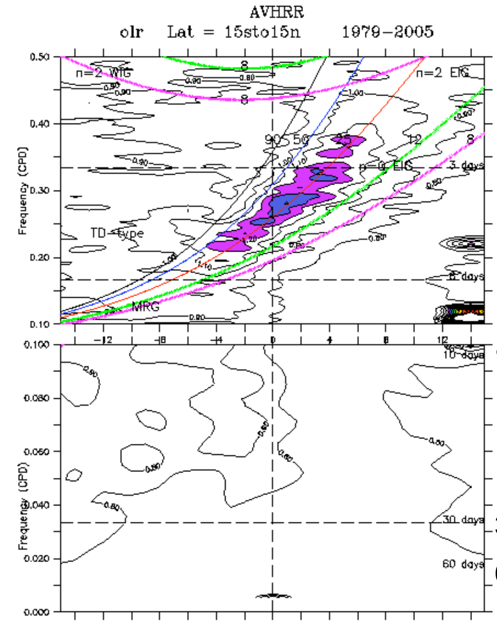
10
30
60

W Zonal Wave No. E

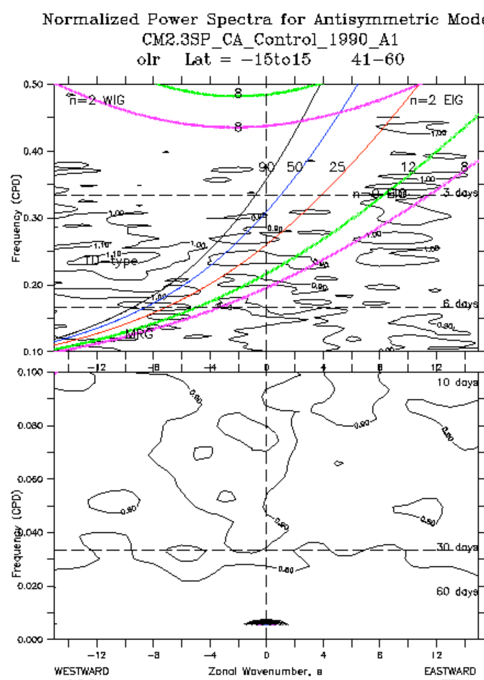
OLR Asym Modes



CM2.1
2deg x 1 deg

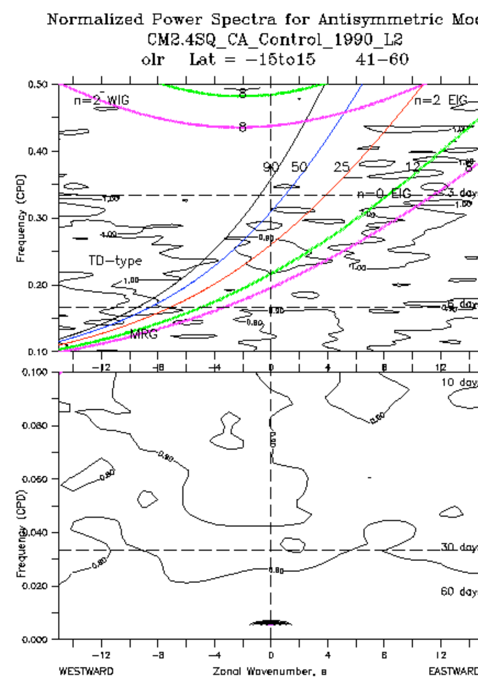


Obs



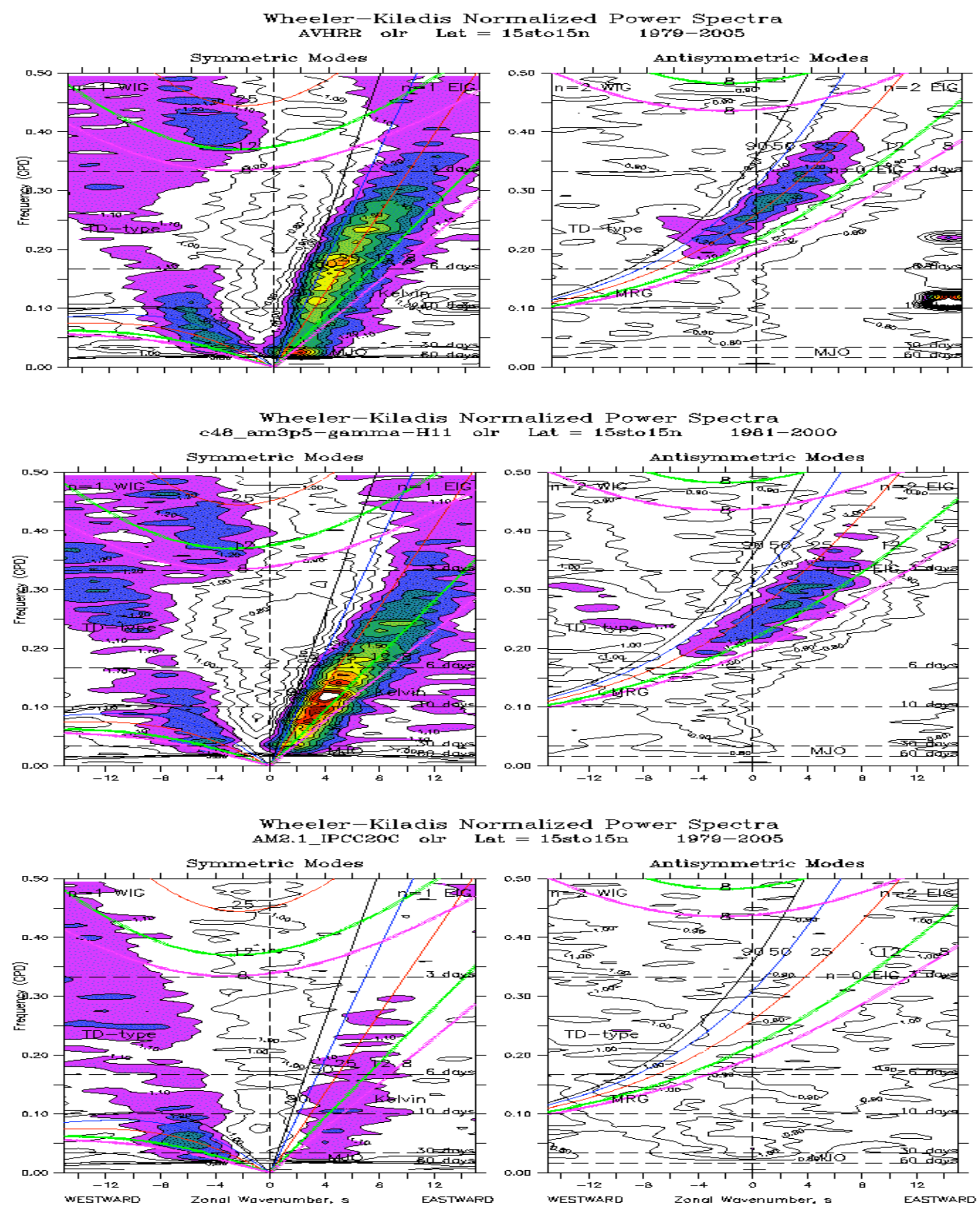
CM2.3
1deg x 1 deg

W Zonal Wave No. E



CM2.4
1deg x .25 deg

W Zonal Wave No. E



OBS

AM3+Modified deep convection closure

Dramatic improvement

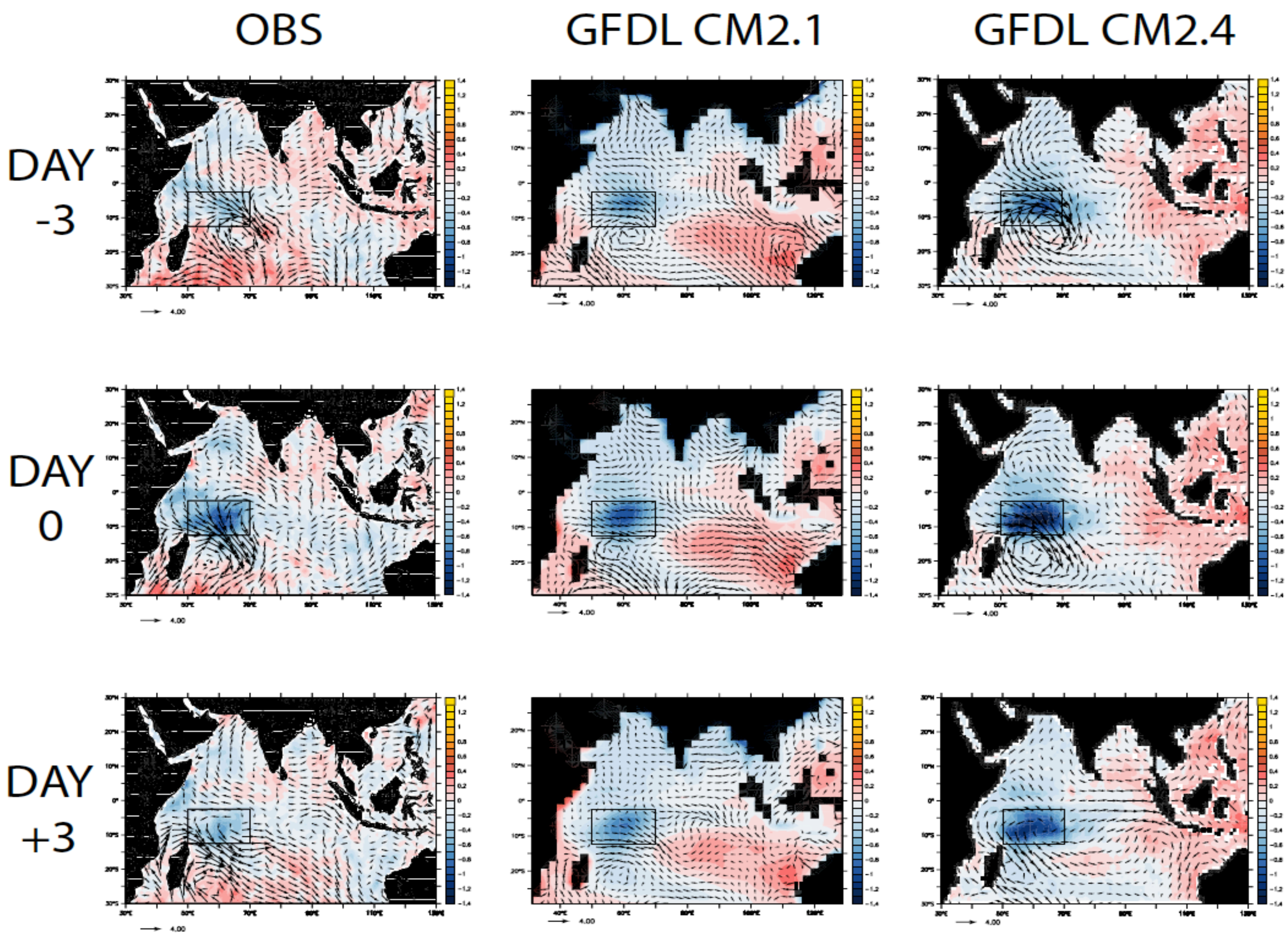
AM3+

More sensitive to physics then res

AM2.1

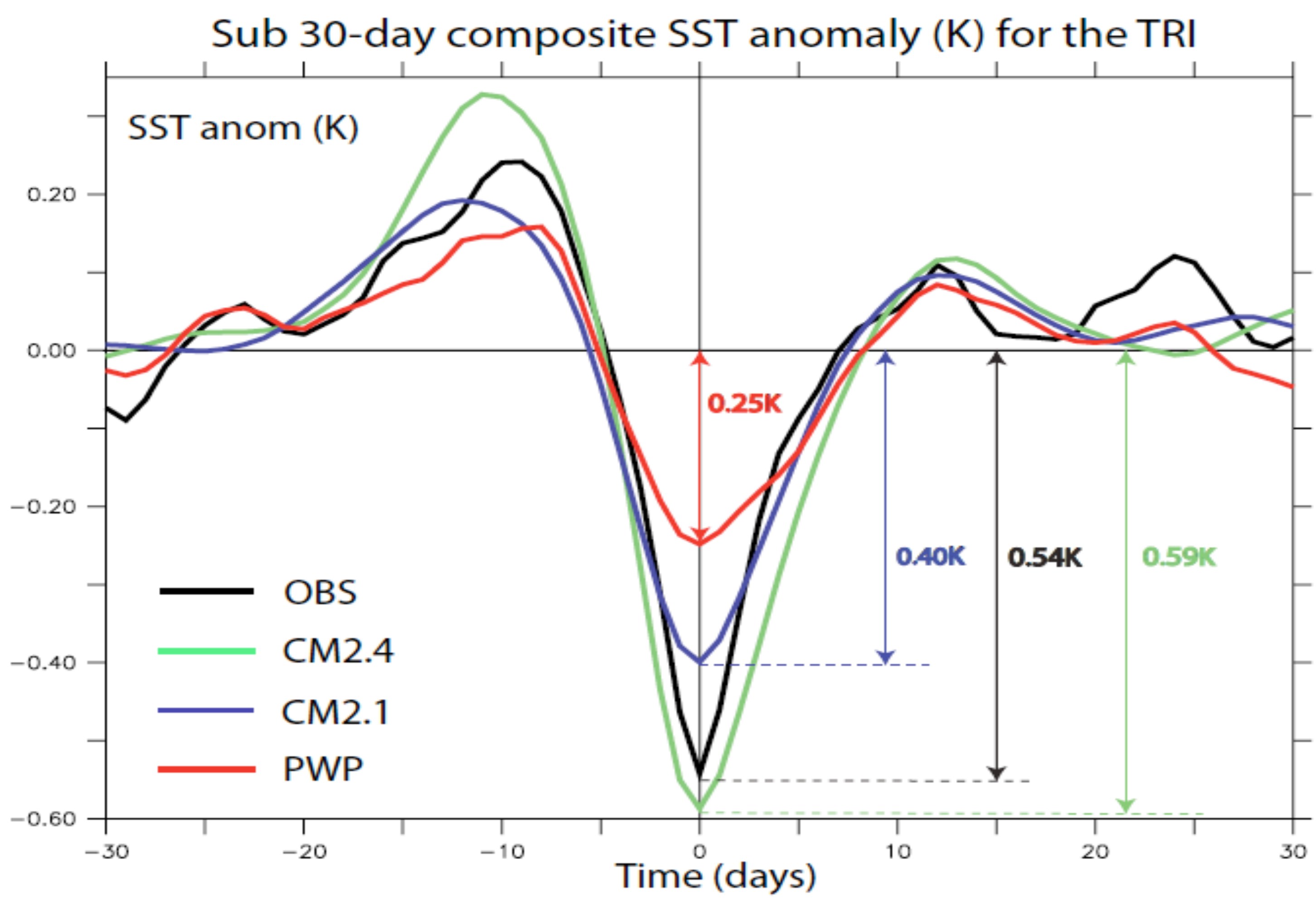
Unfortunately these same modifications often cause a deterioration in the representation of mean climate and other longer time scale features.

Composite Cooling Events in Obs and GFDL Models



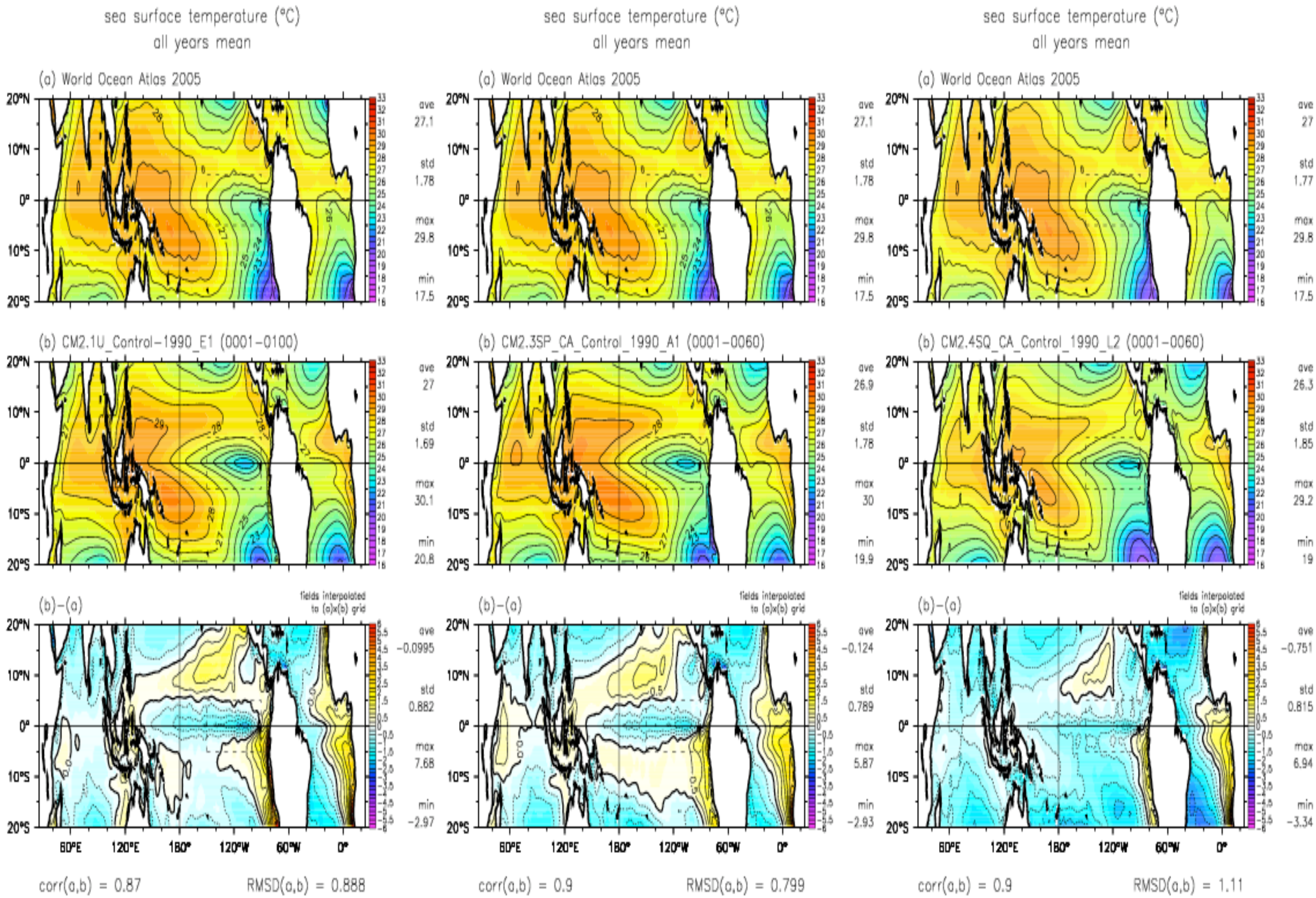
Ian Lloyd, Princeton University

Does intraseasonal SST variability in the thermocline ridge region influence the MJO, or are oceanic changes largely unimportant to the subsequent evolution of the MJO?

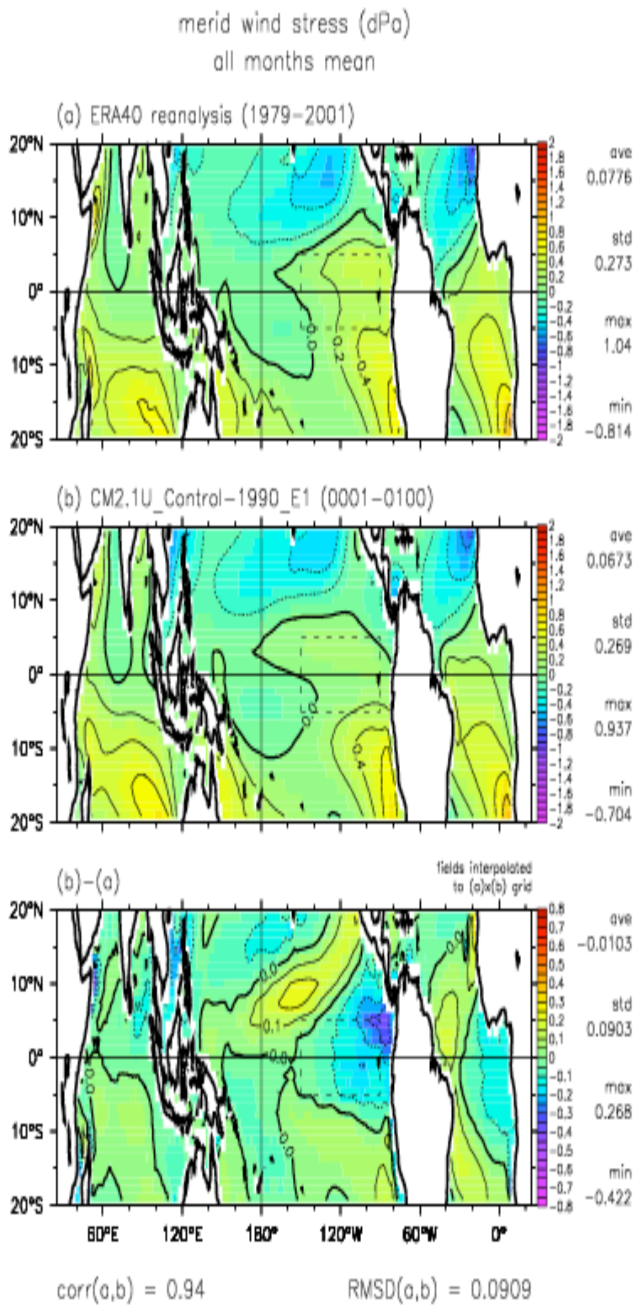


Ian Lloyd, Princeton University

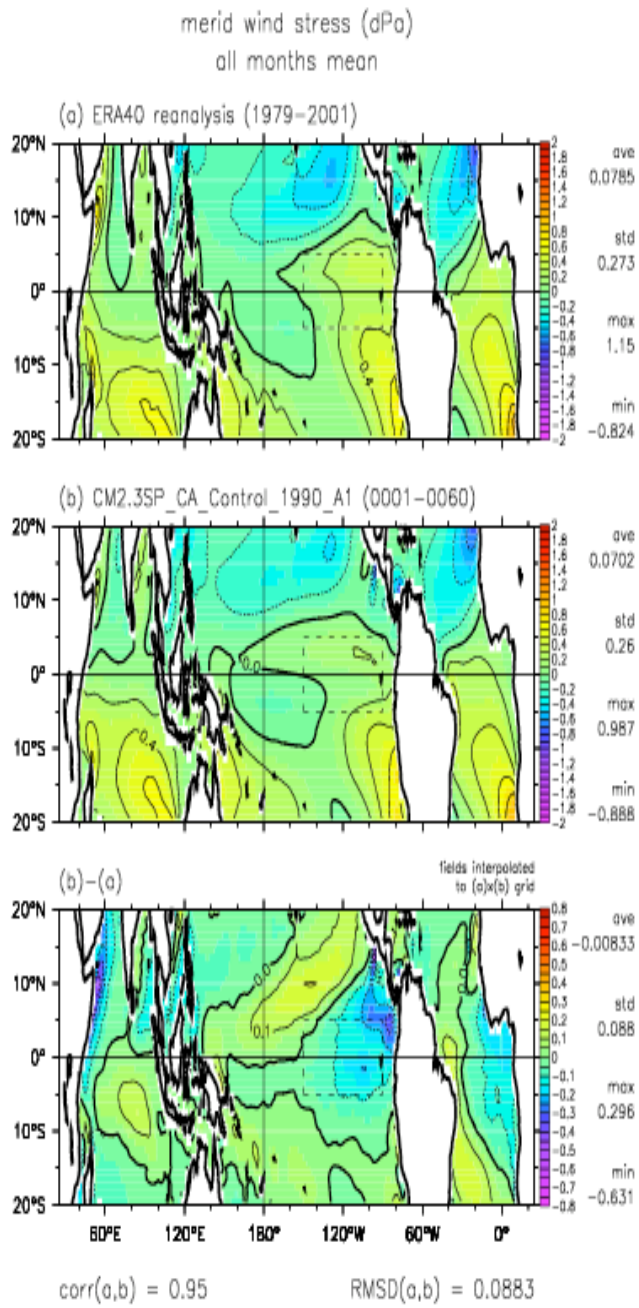
Interannual



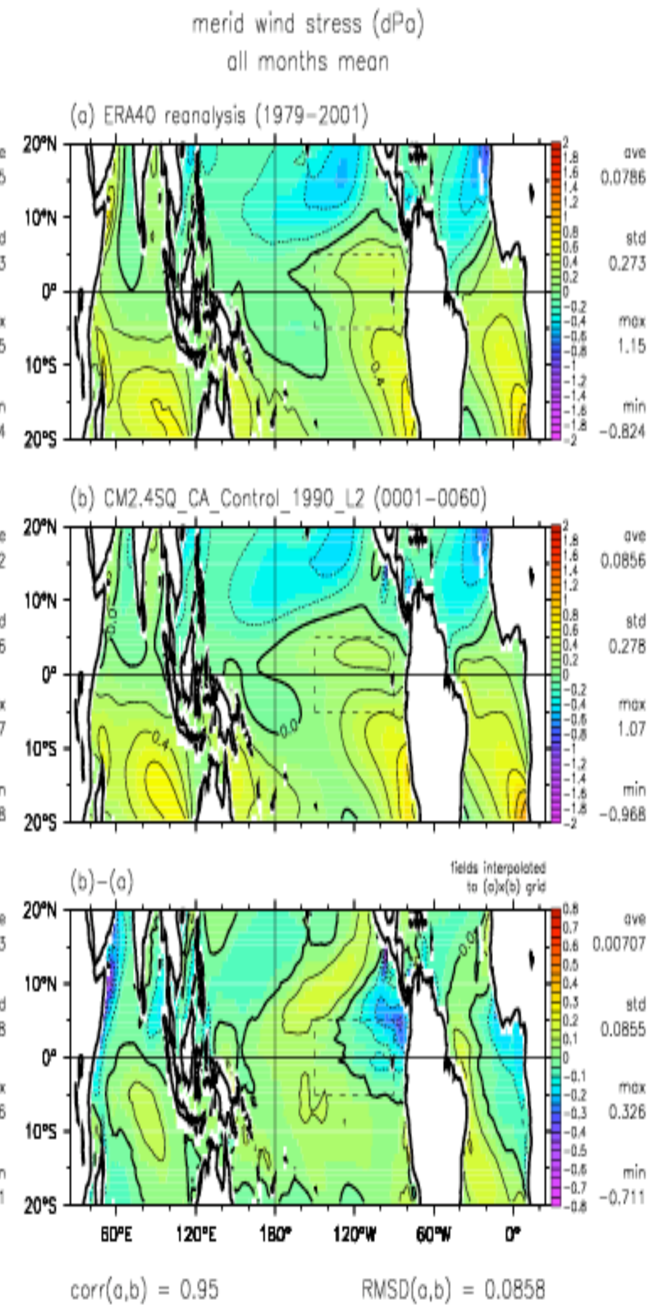
CM2.1 CM2.3 CM2.4



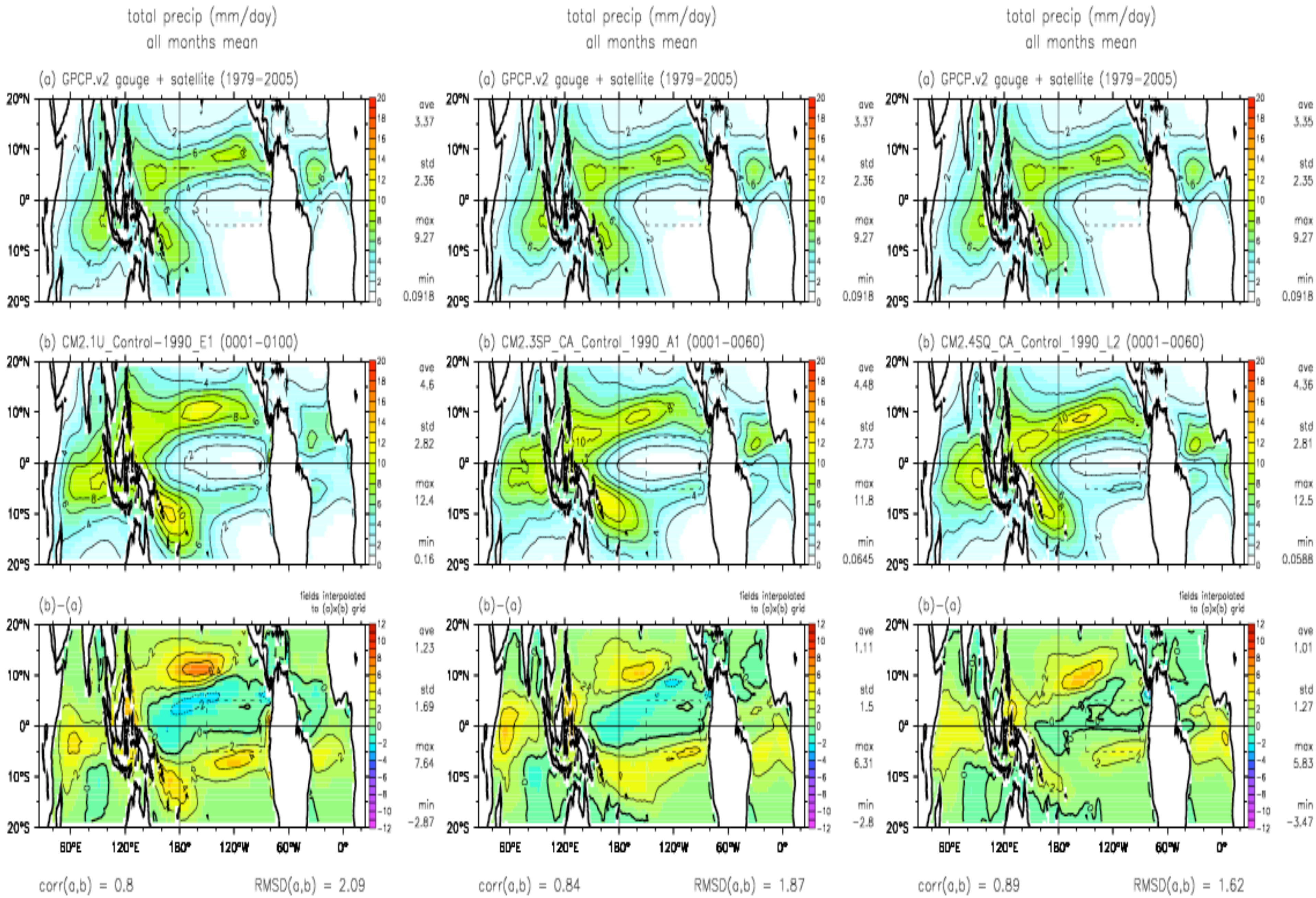
CM2.1



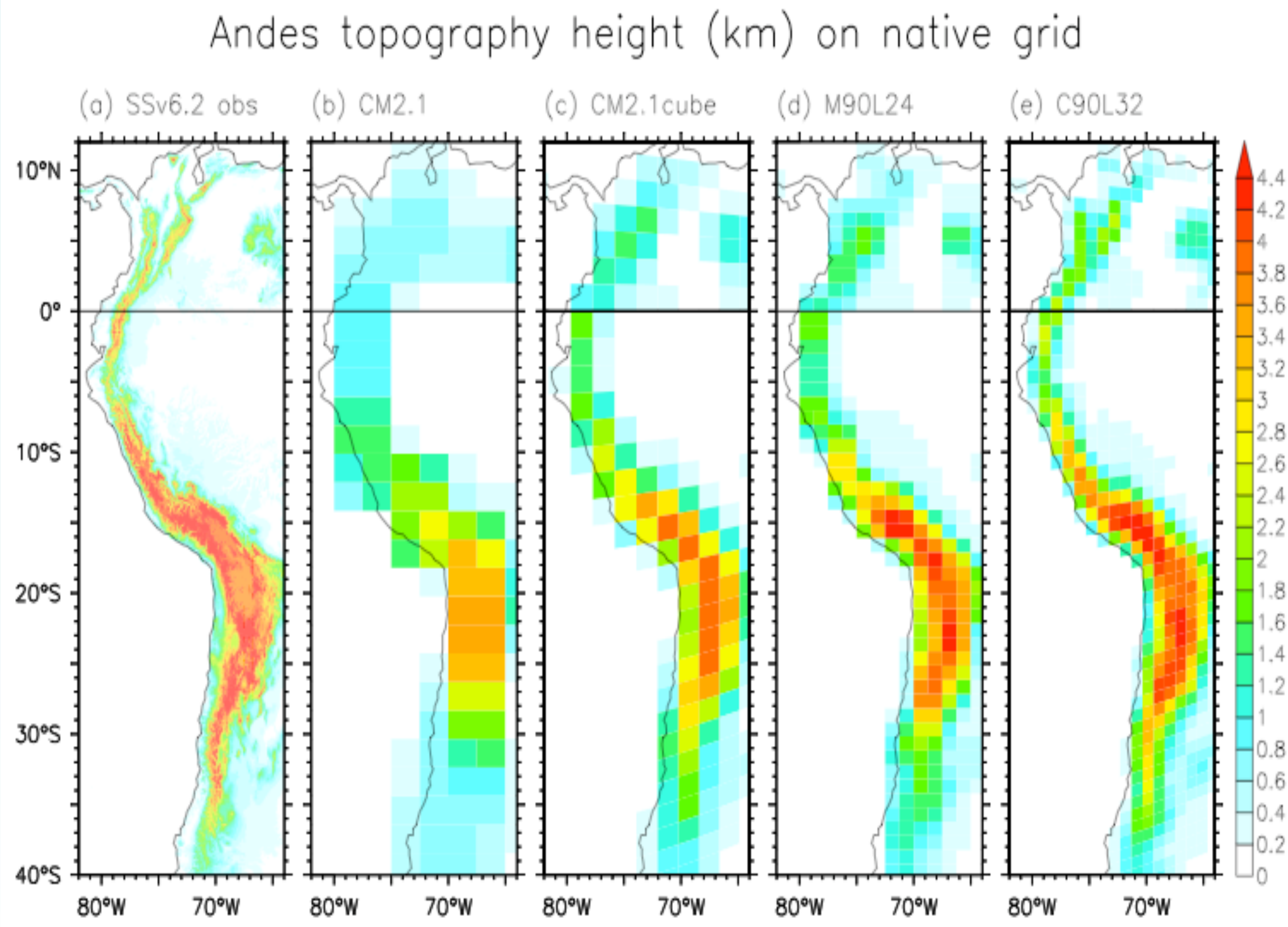
CM2.3



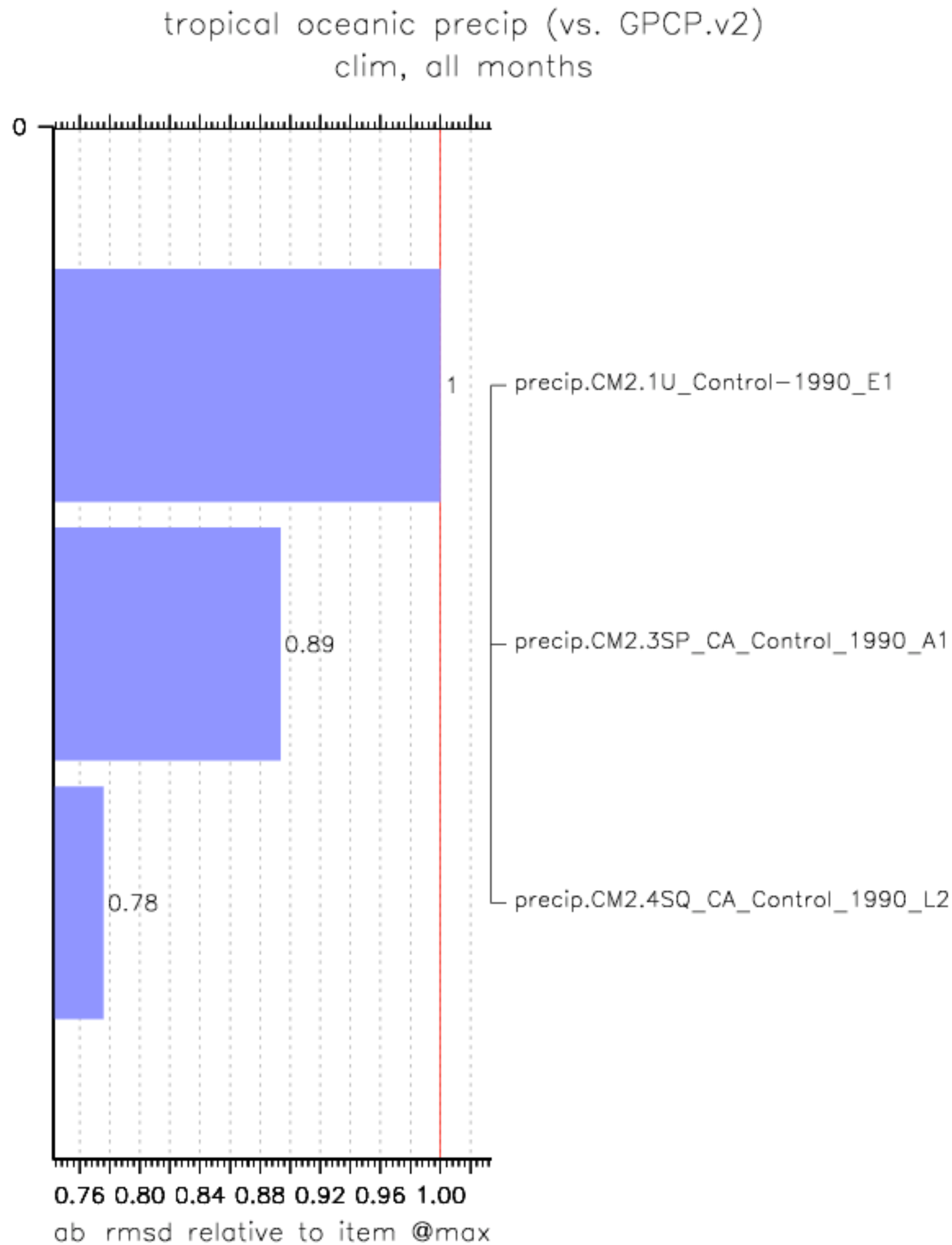
CM2.4



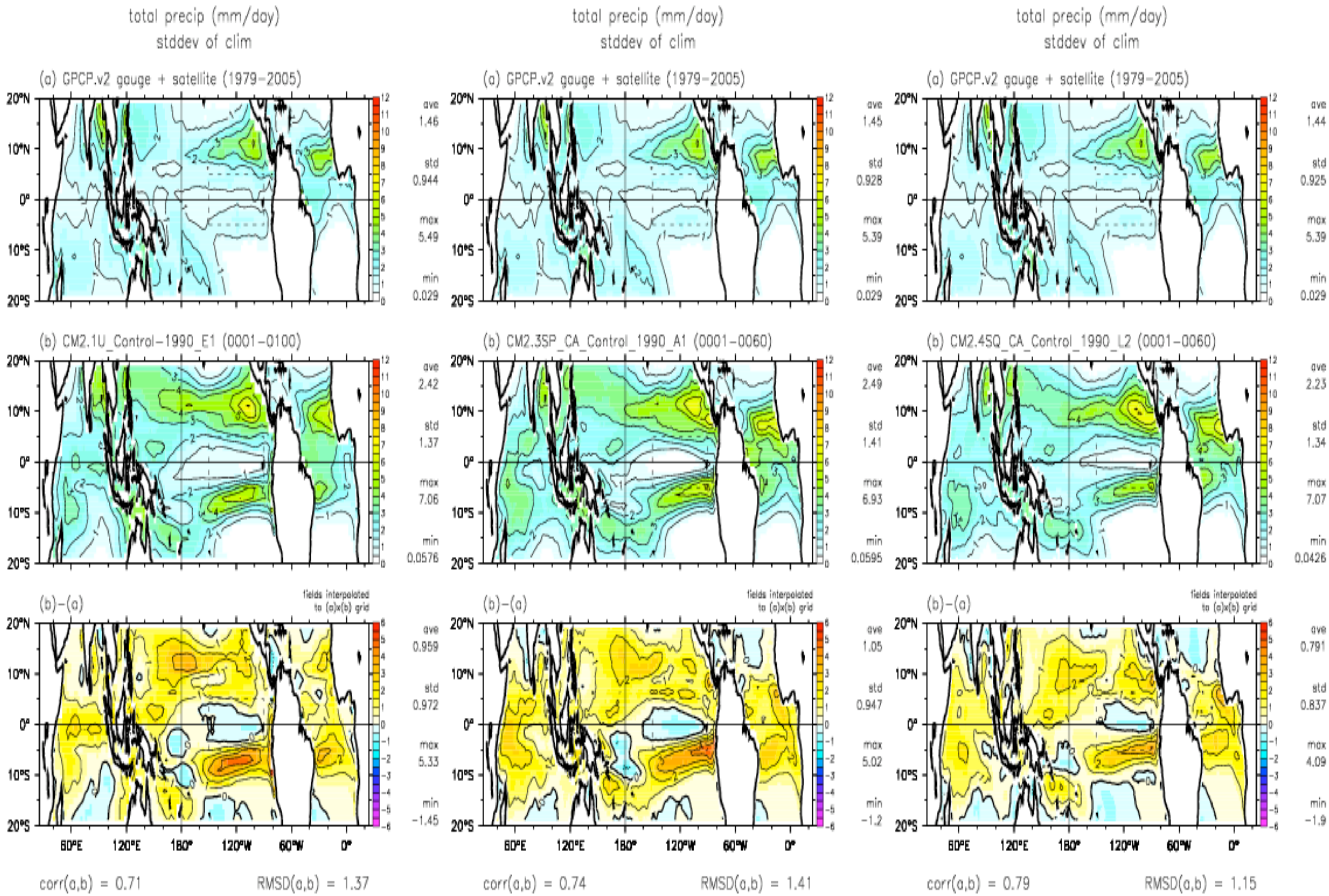
total precip (mm/day)
all months mean
(a) GPCP.v2 gauge + satellite (1979-2005)
ave 3.37
std 2.36
max 9.27
min 0.0918
(b) CM2.1U_Control-1990_E1 (0001-0100)
ave 4.6
std 2.82
max 12.4
min 0.16
(b)-(a)
fields interpolated to (a)x(b) grid
ave 1.23
std 1.69
max 7.64
min -2.87
corr(a,b) = 0.8
RMSD(a,b) = 2.09
total precip (mm/day)
all months mean
(a) GPCP.v2 gauge + satellite (1979-2005)
ave 3.37
std 2.36
max 9.27
min 0.0918
(b) CM2.3SP_CA_Control_1990_A1 (0001-0060)
ave 4.48
std 2.73
max 11.8
min 0.0645
(b)-(a)
fields interpolated to (a)x(b) grid
ave 1.11
std 1.5
max 6.31
min -2.8
corr(a,b) = 0.84
RMSD(a,b) = 1.87
total precip (mm/day)
all months mean
(a) GPCP.v2 gauge + satellite (1979-2005)
ave 3.35
std 2.35
max 9.27
min 0.0918
(b) CM2.4SQ_CA_Control_1990_L2 (0001-0060)
ave 4.36
std 2.81
max 12.5
min 0.0588
(b)-(a)
fields interpolated to (a)x(b) grid
ave 1.01
std 1.27
max 5.83
min -3.47
corr(a,b) = 0.89
RMSD(a,b) = 1.62
20°N
10°N
0°
10°S
20°S
60°E
120°E
180°
120°W
60°W
0°



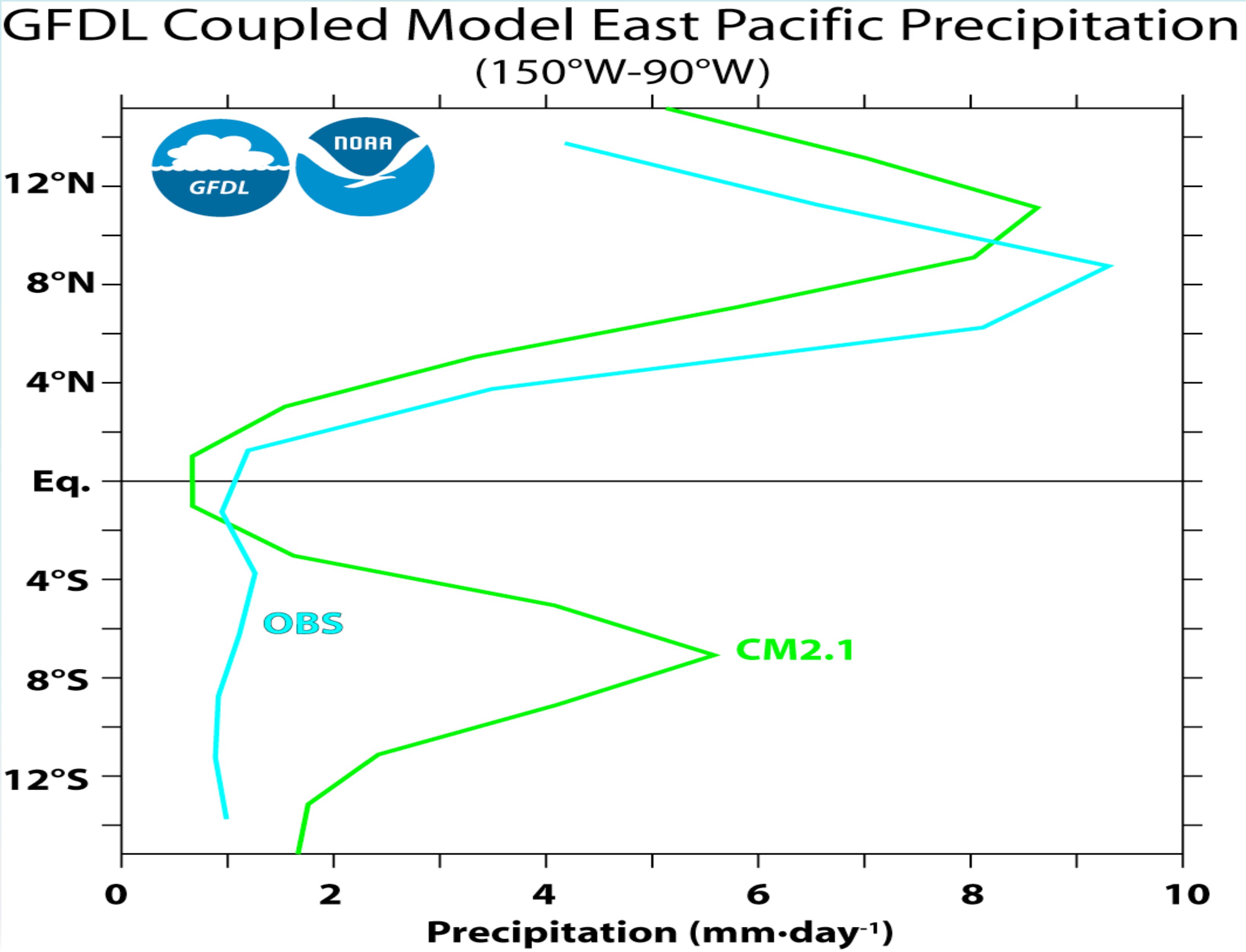
Andes topography height (km) on native grid
(a) SSv6.2 obs
(b) CM2.1
(c) CM2.1cube
(d) M90L24
(e) C90L32
10°N
0°
10°S
20°S
30°S
40°S
80°W
70°W
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0



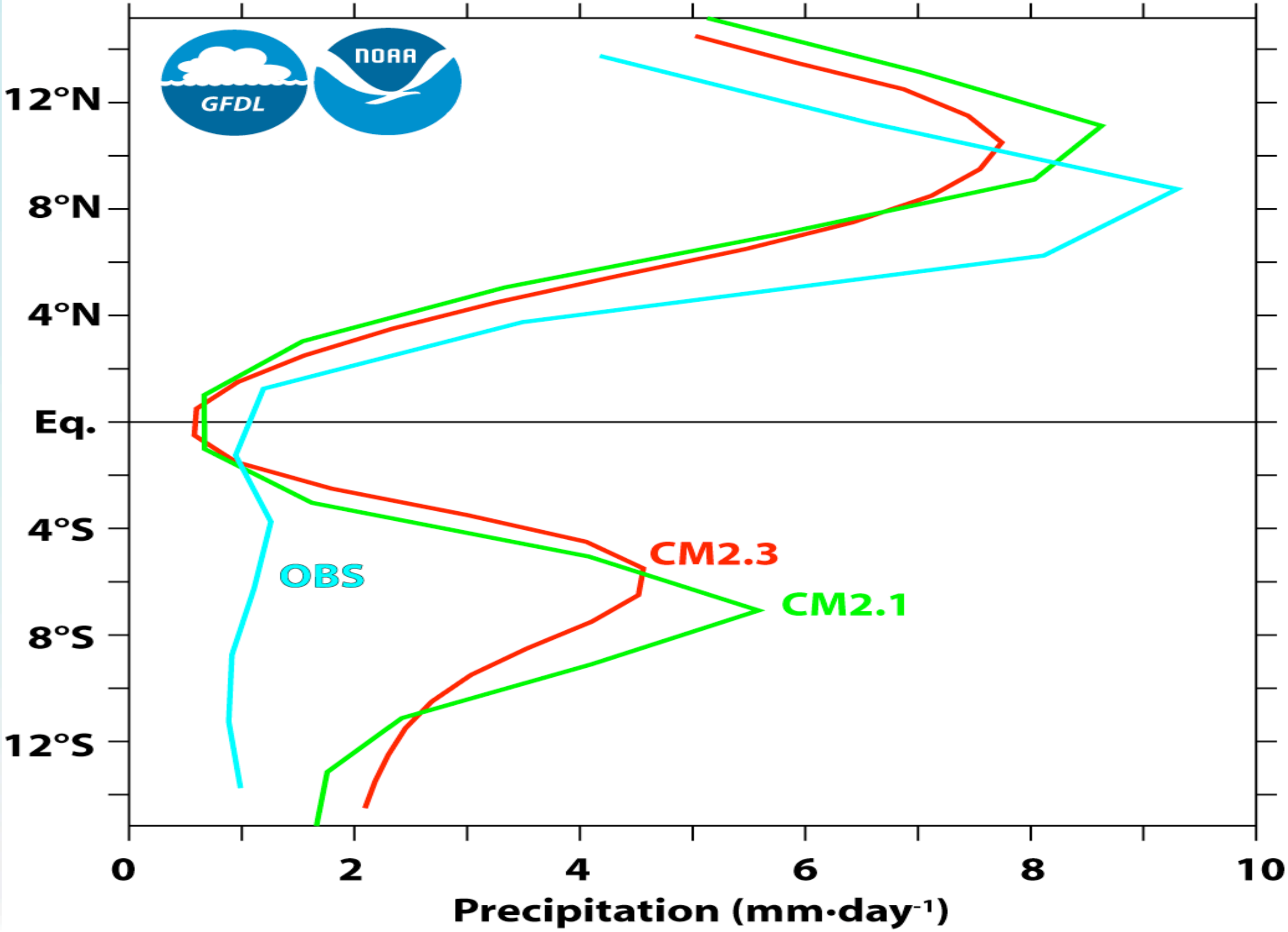
tropical oceanic precip (vs. GPCP.v2)
clim, all months
0
1
0.89
0.78
precip.CM2.1U_Control−1990_E1
precip.CM2.3SP_CA_Control_1990_A1
precip.CM2.4SQ_CA_Control_1990_L2
0.76 0.80 0.84 0.88 0.92 0.96 1.00
ab_rmsd relative to item @max

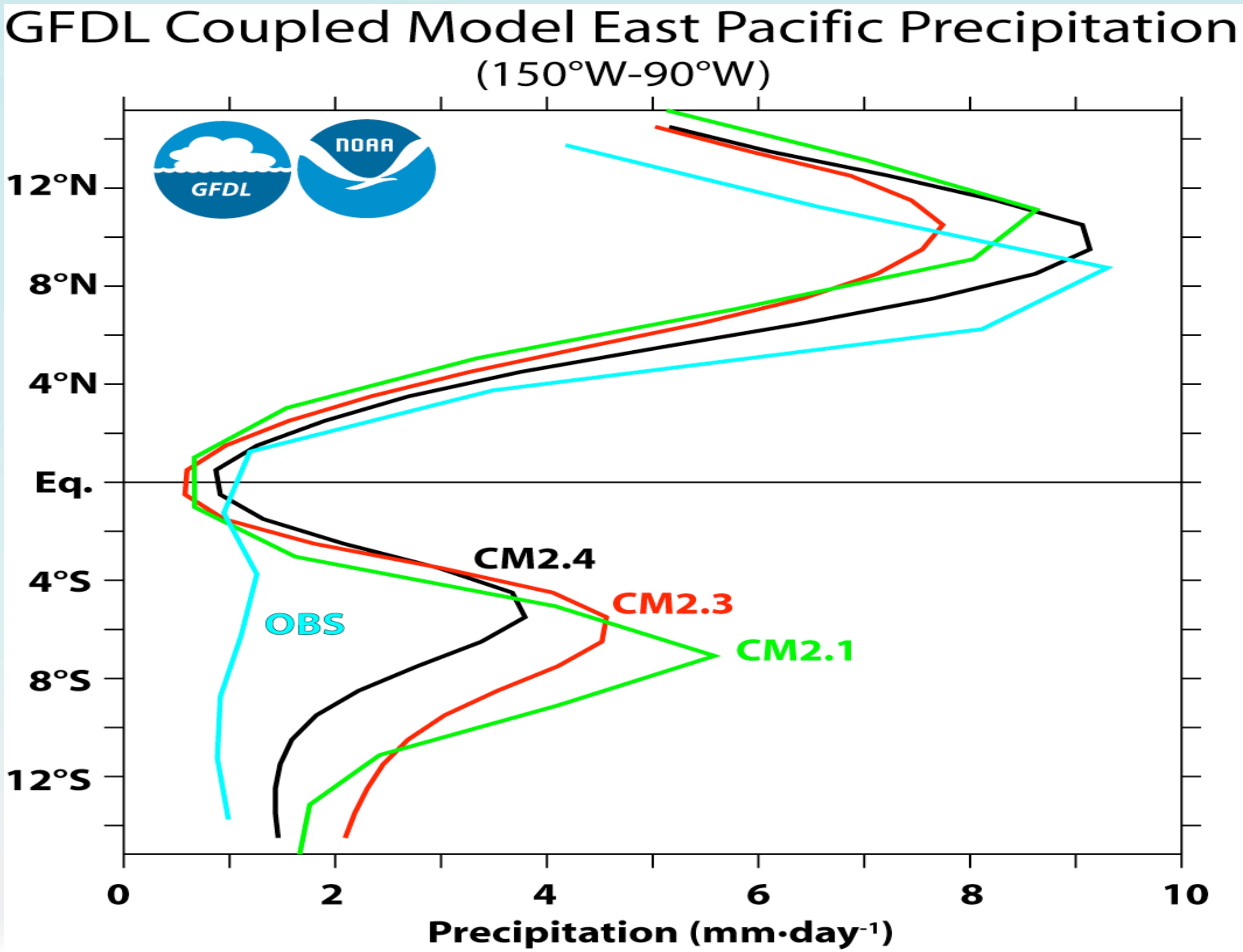


total precip (mm/day)
stddev of clim
(a) GPCP.v2 gauge + satellite (1979-2005)
ave 1.46 std 0.944 max 5.49 min 0.029
(b) CM2.1U_Control-1990_E1 (0001-0100)
ave 2.42 std 1.37 max 7.06 min 0.0576
(b)-(a)
fields interpolated to (a)x(b) grid
ave 0.959 std 0.972 max 5.33 min -1.45
corr(a,b) = 0.71
RMSD(a,b) = 1.37
total precip (mm/day)
stddev of clim
(a) GPCP.v2 gauge + satellite (1979-2005)
ave 1.45 std 0.928 max 5.39 min 0.029
(b) CM2.3SP_CA_Control_1990_A1 (0001-0060)
ave 2.49 std 1.41 max 6.93 min 0.0595
(b)-(a)
fields interpolated to (a)x(b) grid
ave 1.05 std 0.947 max 5.02 min -1.2
corr(a,b) = 0.74
RMSD(a,b) = 1.41
total precip (mm/day)
stddev of clim
(a) GPCP.v2 gauge + satellite (1979-2005)
ave 1.44 std 0.925 max 5.39 min 0.029
(b) CM2.4SQ_CA_Control_1990_L2 (0001-0060)
ave 2.23 std 1.34 max 7.07 min 0.0426
(b)-(a)
fields interpolated to (a)x(b) grid
ave 0.791 std 0.837 max 4.09 min -1.9
corr(a,b) = 0.79
RMSD(a,b) = 1.15
20°N 10°N 0° 10°S 20°S
60°E 120°E 180° 120°W 60°W 0°

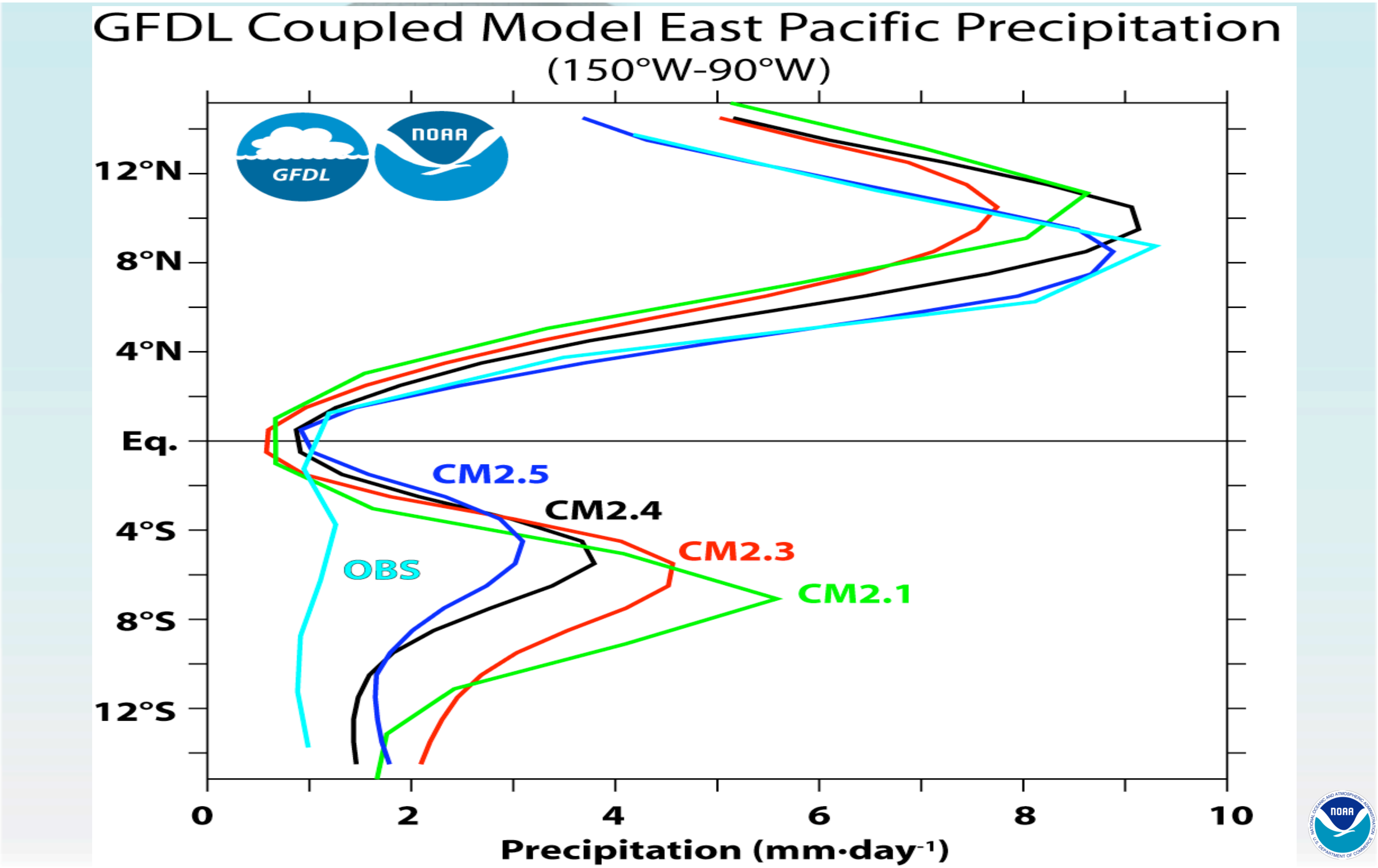

GFDL Coupled Model East Pacific Precipitation
(150°W-90°W)
GFDL
NOAA
12°N
8°N
4°N
Eq.
4°S
8°S
12°S
OBS
CM2.1
0
2
4
6
8
10
Precipitation (mm·day-1)

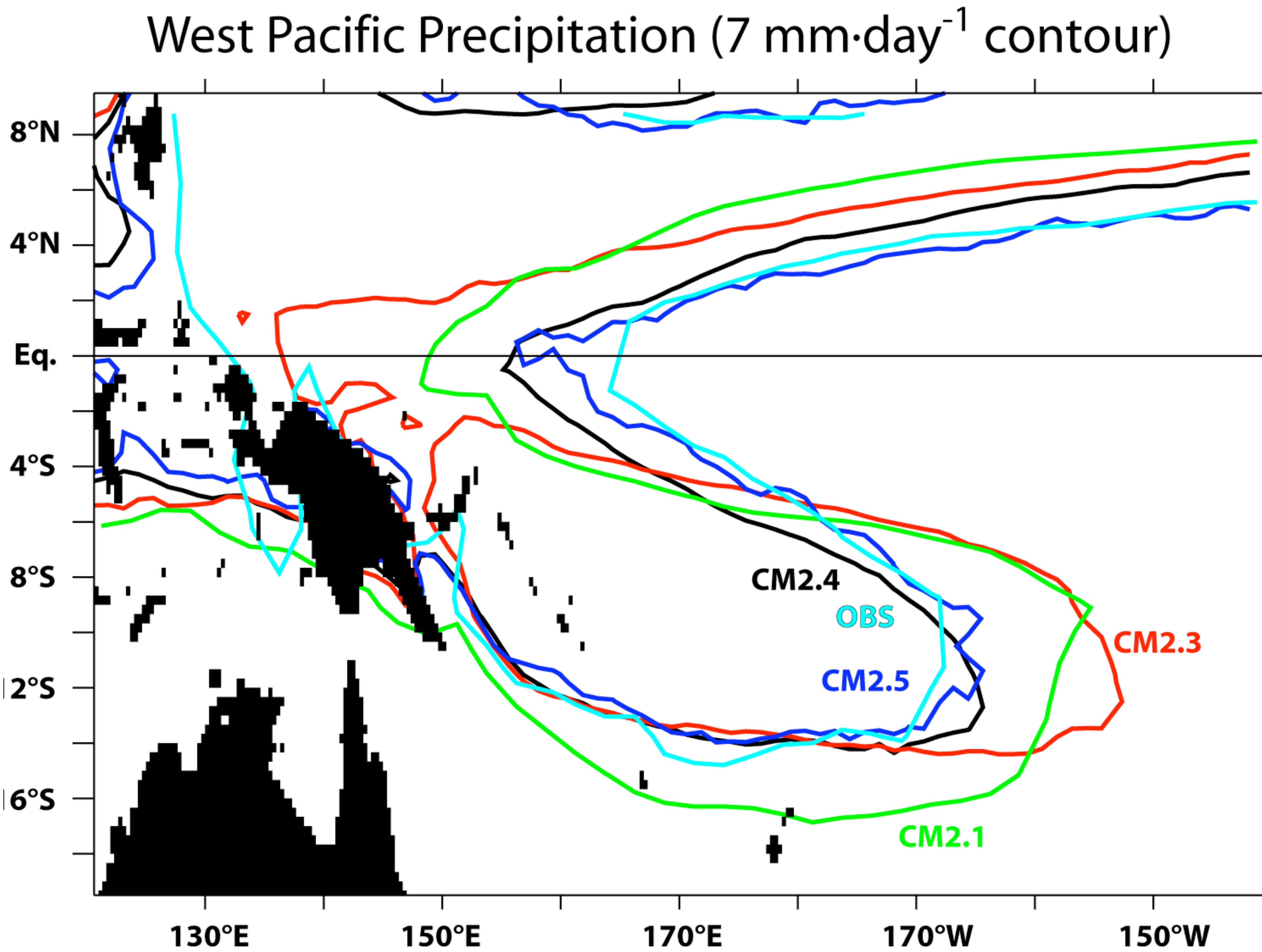
GFDL Coupled Model East Pacific Precipitation
(150°W-90°W)



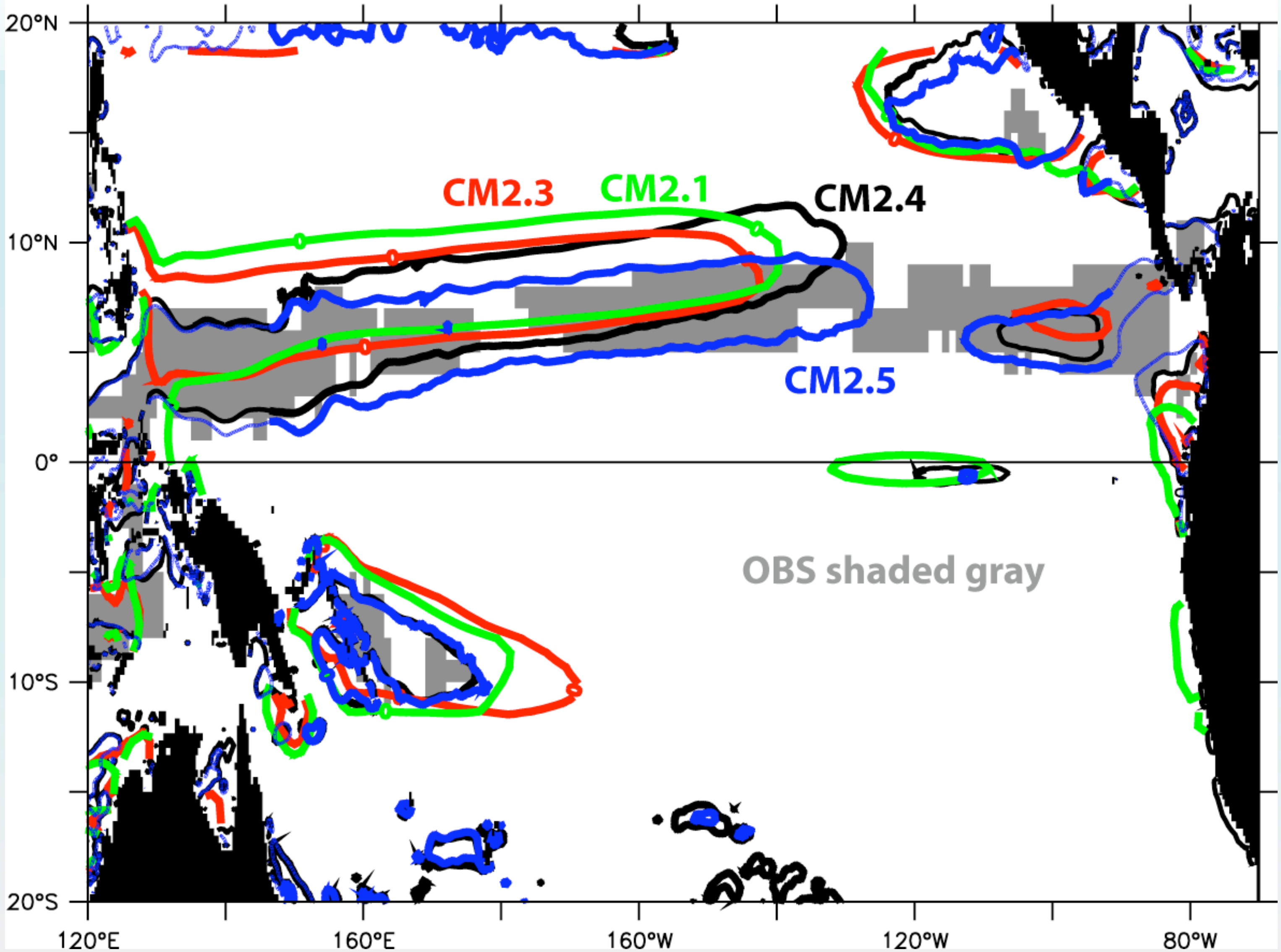

GFDL Coupled Model East Pacific Precipitation
(150°W-90°W)
GFDL
NOAA
12°N
8°N
4°N
Eq.
4°S
8°S
12°S
CM2.4
CM2.3
CM2.1
OBS
0
2
4
6
8
10
Precipitation (mm·day⁻¹)

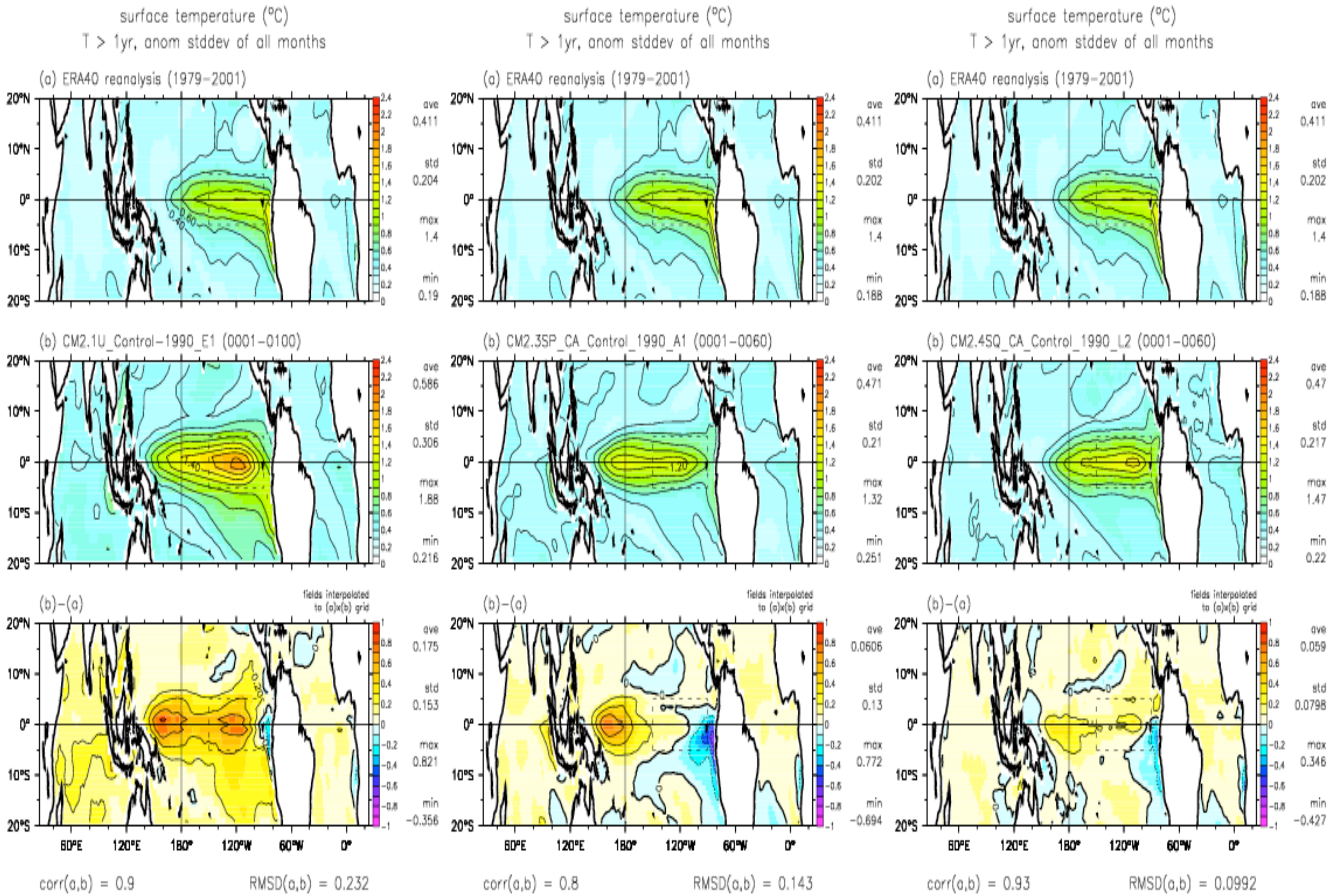
ITCZ moves close to equator in both hemispheres, in addition to weakening SEP ITCZ. Meridional asymmetry seems to be more influenced by ocean res. than atmos. res. (compare CM2.3 is much more symmetric than either CM2.4 or CM2.5).



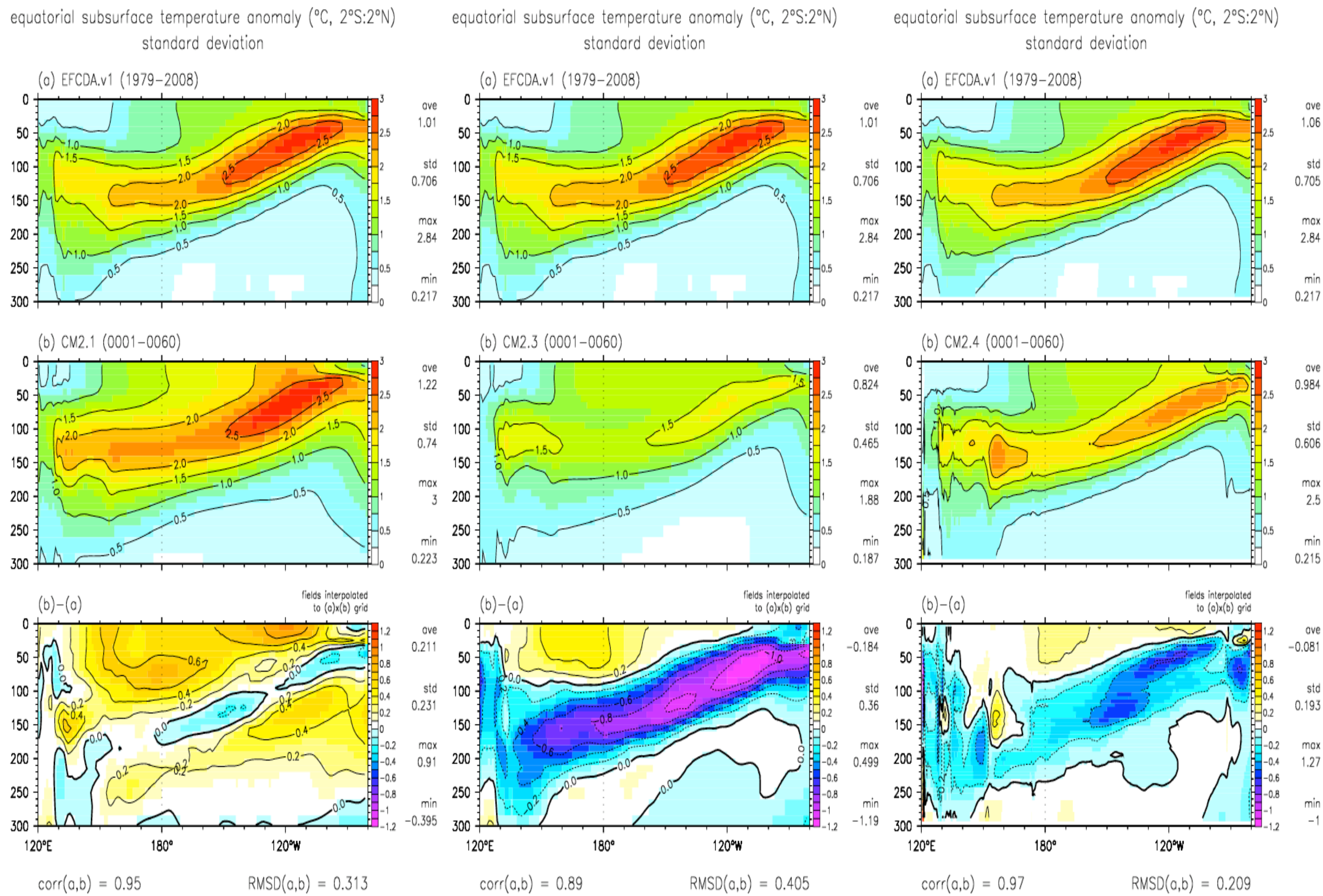

West Pacific Precipitation (7 mm·day-1 contour)
8°N
4°N
Eq.
4°S
8°S
12°S
16°S
130°E
150°E
170°E
170°W
150°W
CM2.4
OBS
CM2.5
CM2.3
CM2.1

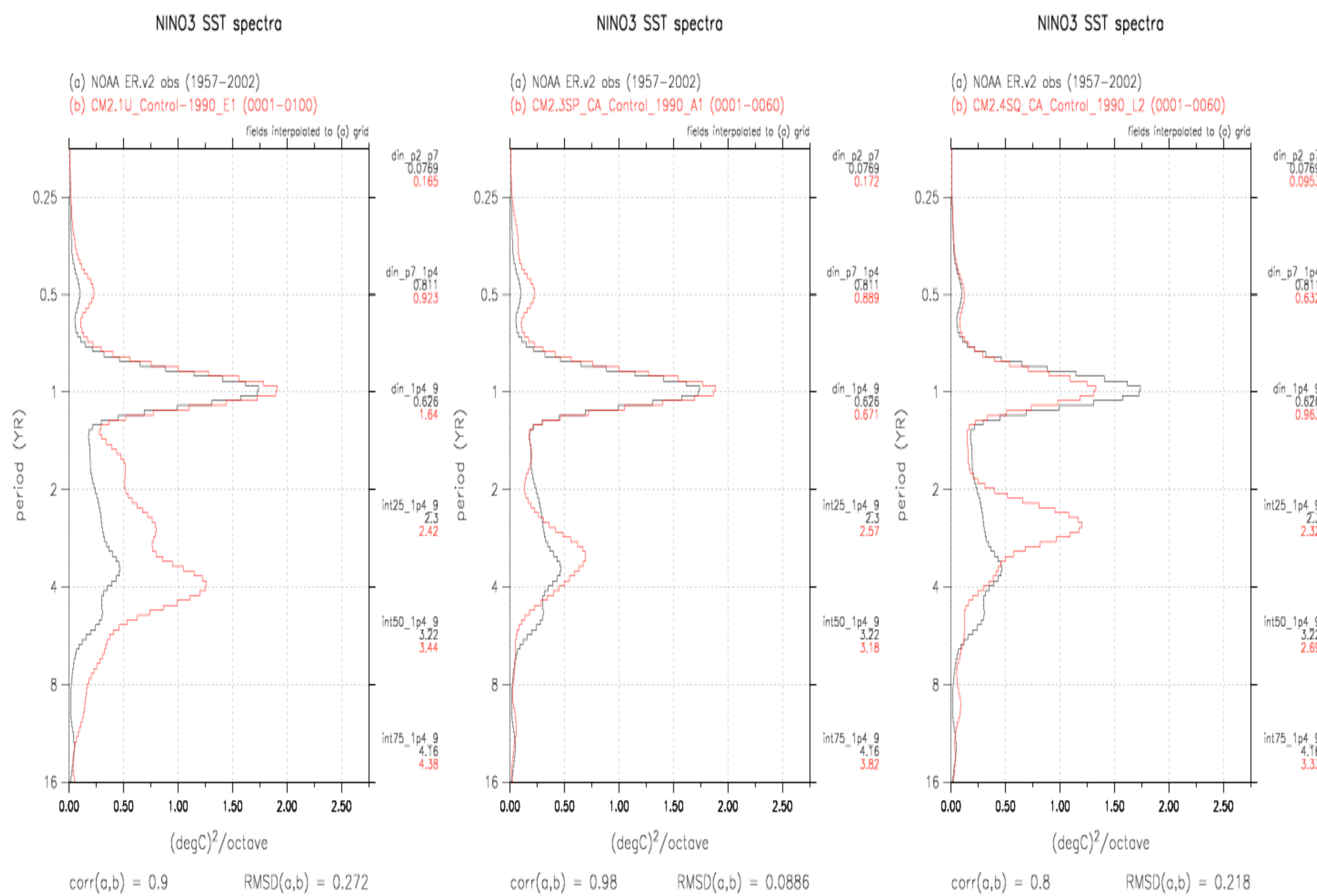
Surface zonal current (0 m·s^{-1} contour)



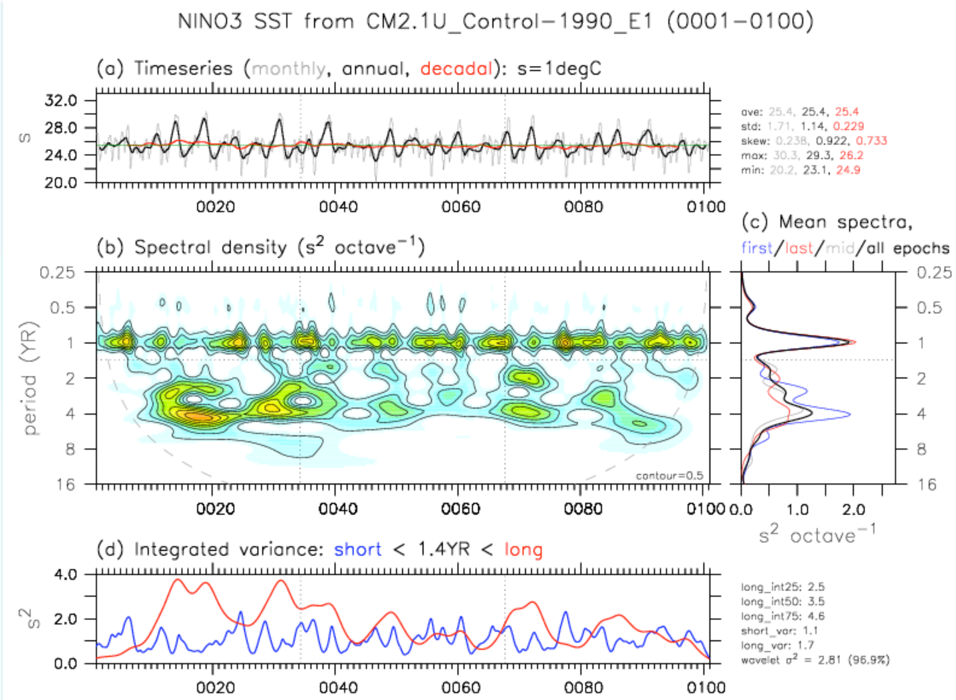


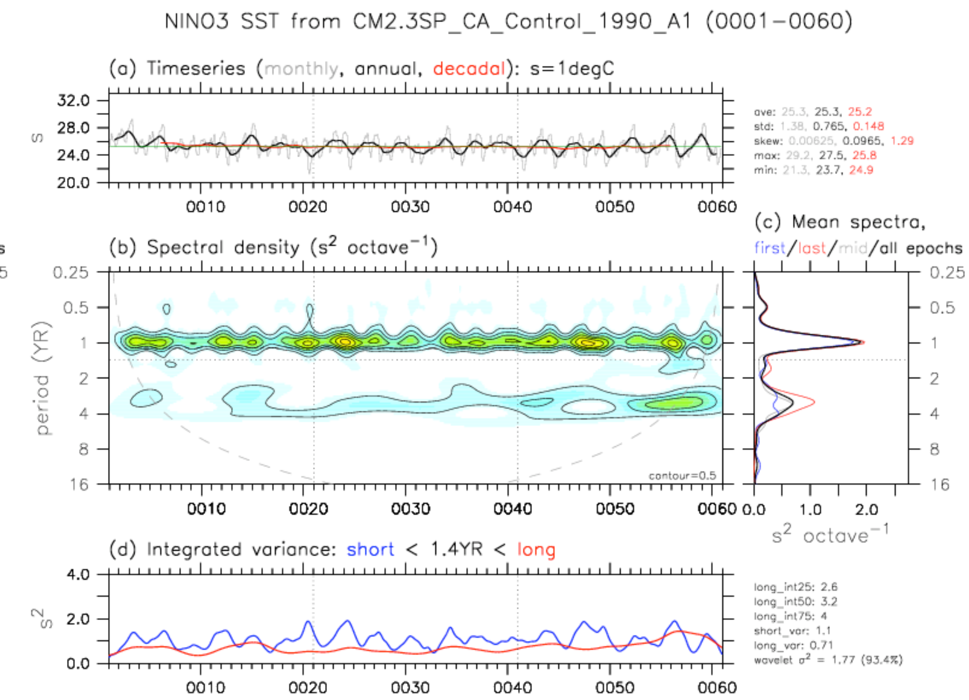
surface temperature (°C)
T > 1yr, anom stddev of all months
(a) ERA40 reanalysis (1979-2001)
ave 0.411
std 0.204
max 1.4
min 0.19
(b) CM2.1U_Control-1990_E1 (0001-0100)
ave 0.586
std 0.306
max 1.88
min 0.216
(b)-(a)
fields interpolated to (a)x(b) grid
ave 0.175
std 0.153
max 0.821
min -0.356
corr(a,b) = 0.9
RMSD(a,b) = 0.232
surface temperature (°C)
T > 1yr, anom stddev of all months
(a) ERA40 reanalysis (1979-2001)
ave 0.411
std 0.202
max 1.4
min 0.188
(b) CM2.3SP_CA_Control_1990_A1 (0001-0060)
ave 0.471
std 0.21
max 1.32
min 0.251
(b)-(a)
fields interpolated to (a)x(b) grid
ave 0.0606
std 0.13
max 0.772
min -0.694
corr(a,b) = 0.8
RMSD(a,b) = 0.143
surface temperature (°C)
T > 1yr, anom stddev of all months
(a) ERA40 reanalysis (1979-2001)
ave 0.411
std 0.202
max 1.4
min 0.188
(b) CM2.4SQ_CA_Control_1990_L2 (0001-0060)
ave 0.47
std 0.217
max 1.47
min 0.22
(b)-(a)
fields interpolated to (a)x(b) grid
ave 0.059
std 0.0798
max 0.346
min -0.427
corr(a,b) = 0.93
RMSD(a,b) = 0.0992

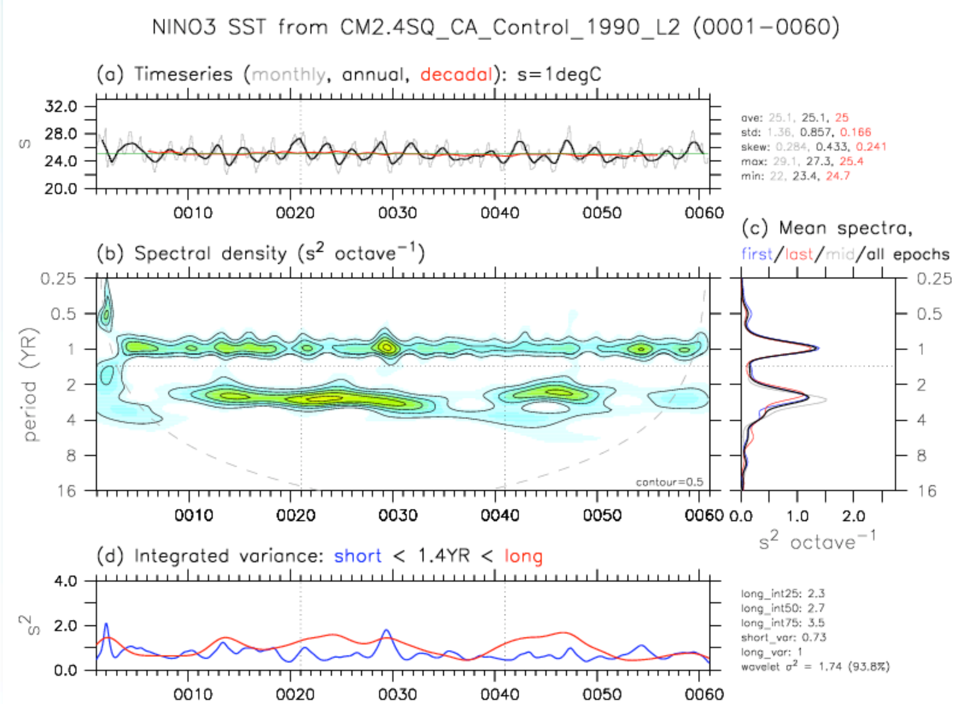

equatorial subsurface temperature anomaly (°C, 2°S:2°N)
standard deviation
(a) EFCDA.v1 (1979–2008)
ave 1.01
std 0.706
max 2.84
min 0.217
(b) CM2.1 (0001–0060)
ave 1.22
std 0.74
max 3
min 0.223
(b)–(a)
fields interpolated to (a)x(b) grid
ave 0.211
std 0.231
max 0.91
min −0.395
120°E
180°
120°W
corr(a,b) = 0.95
RMSD(a,b) = 0.313
equatorial subsurface temperature anomaly (°C, 2°S:2°N)
standard deviation
(a) EFCDA.v1 (1979–2008)
ave 1.01
std 0.706
max 2.84
min 0.217
(b) CM2.3 (0001–0060)
ave 0.824
std 0.465
max 1.88
min 0.187
(b)–(a)
fields interpolated to (a)x(b) grid
ave −0.184
std 0.36
max 0.499
min −1.19
120°E
180°
120°W
corr(a,b) = 0.89
RMSD(a,b) = 0.405
equatorial subsurface temperature anomaly (°C, 2°S:2°N)
standard deviation
(a) EFCDA.v1 (1979–2008)
ave 1.06
std 0.705
max 2.84
min 0.217
(b) CM2.4 (0001–0060)
ave 0.984
std 0.606
max 2.5
min 0.215
(b)–(a)
fields interpolated to (a)x(b) grid
ave −0.081
std 0.193
max 1.27
min −1
120°E
180°
120°W
corr(a,b) = 0.97
RMSD(a,b) = 0.209

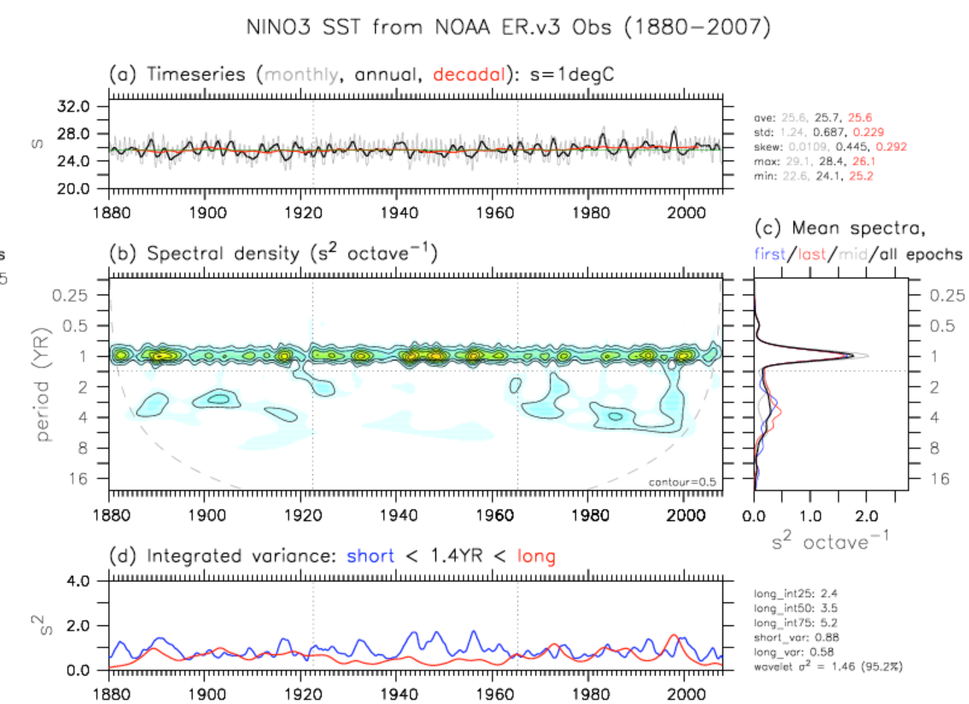


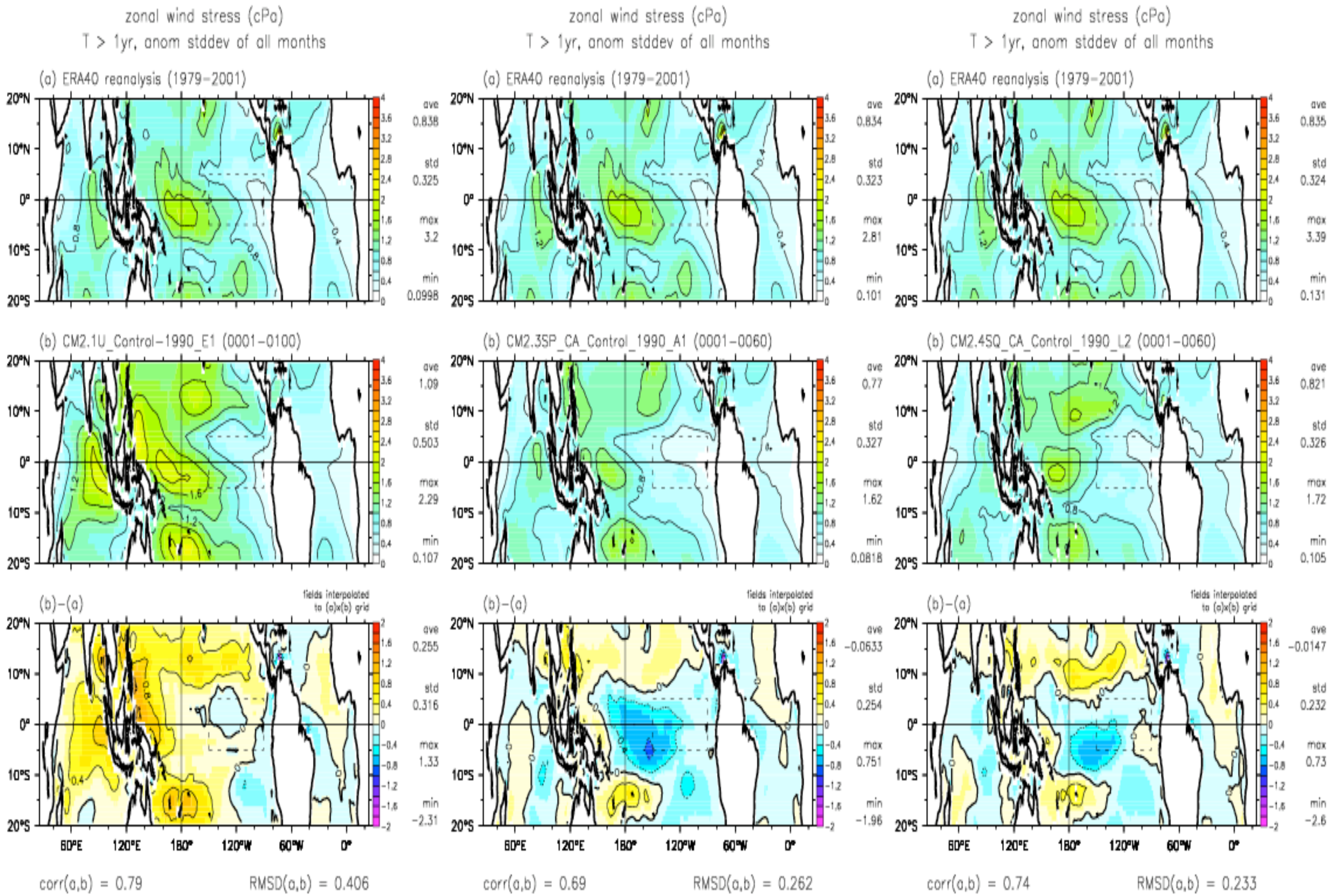
NINO3 SST spectra
(a) NOAA ER.v2 obs (1957-2002)
(b) CM2.1U_Control-1990_E1 (0001-0100)
fields interpolated to (a) grid
din_p2_p7 0.0769 0.165
din_p7_1p4 0.811 0.923
din_1p4_9 0.626 1.64
int25_1p4_9 2.3 2.42
int50_1p4_9 3.22 3.44
int75_1p4_9 4.16 4.38
period (YR)
(degC)2/octave
corr(a,b) = 0.9
RMSD(a,b) = 0.272
NINO3 SST spectra
(a) NOAA ER.v2 obs (1957-2002)
(b) CM2.3SP_CA_Control_1990_A1 (0001-0060)
fields interpolated to (a) grid
din_p2_p7 0.0769 0.172
din_p7_1p4 0.811 0.889
din_1p4_9 0.626 0.671
int25_1p4_9 2.3 2.57
int50_1p4_9 3.22 3.18
int75_1p4_9 4.16 3.82
period (YR)
(degC)2/octave
corr(a,b) = 0.98
RMSD(a,b) = 0.0886
NINO3 SST spectra
(a) NOAA ER.v2 obs (1957-2002)
(b) CM2.4SQ_CA_Control_1990_L2 (0001-0060)
fields interpolated to (a) grid
din_p2_p7 0.0769 0.0953
din_p7_1p4 0.811 0.632
din_1p4_9 0.626 0.963
int25_1p4_9 2.3 2.32
int50_1p4_9 3.22 2.69
int75_1p4_9 4.16 3.33
period (YR)
(degC)2/octave
corr(a,b) = 0.8
RMSD(a,b) = 0.218

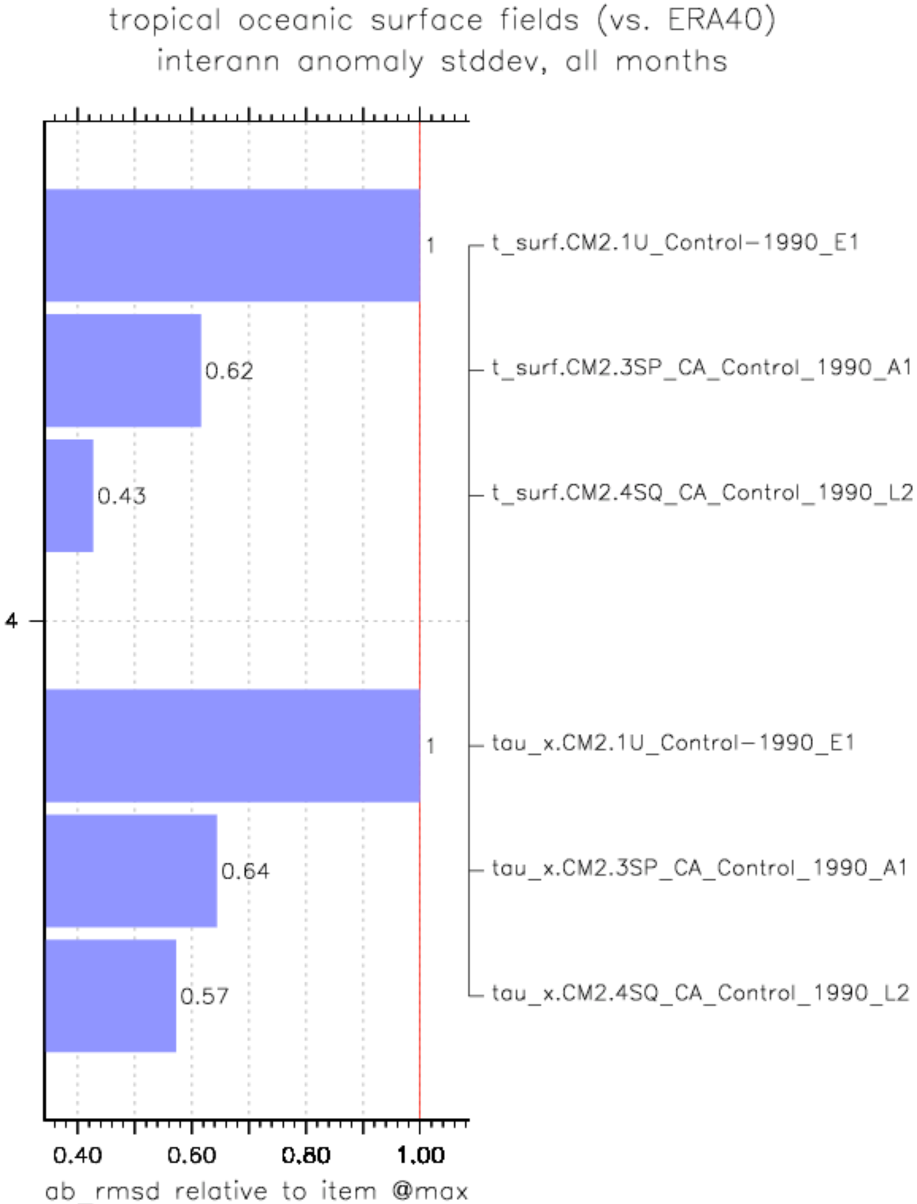

NINO3 SST from CM2.1U_Control-1990_E1 (0001-0100)
(a) Timeseries (monthly, annual, decadal): s=1degC
ave: 25.4, 25.4, 25.4
std: 1.71, 1.14, 0.229
skew: 0.238, 0.922, 0.733
max: 30.3, 29.3, 26.2
min: 20.2, 23.1, 24.9
(b) Spectral density (s² octave⁻¹)
period (YR)
contour=0.5
(c) Mean spectra,
first/last/mid/all epochs
s² octave⁻¹
(d) Integrated variance: short < 1.4YR < long
long_int25: 2.5
long_int50: 3.5
long_int75: 4.6
short_var: 1.1
long_var: 1.7
wavelet σ² = 2.81 (96.9%)


NINO3 SST from CM2.3SP_CA_Control_1990_A1 (0001-0060)
(a) Timeseries (monthly, annual, decadal): s=1degC
ave: 25.3, 25.3, 25.2
std: 1.38, 0.765, 0.148
skew: 0.00625, 0.0965, 1.29
max: 29.2, 27.5, 25.8
min: 21.3, 23.7, 24.9
(b) Spectral density (s² octave⁻¹)
period (YR)
contour=0.5
(c) Mean spectra,
first/last/mid/all epochs
s² octave⁻¹
(d) Integrated variance: short < 1.4YR < long
long_int25: 2.6
long_int50: 3.2
long_int75: 4
short_var: 1.1
long_var: 0.71
wavelet σ² = 1.77 (93.4%)

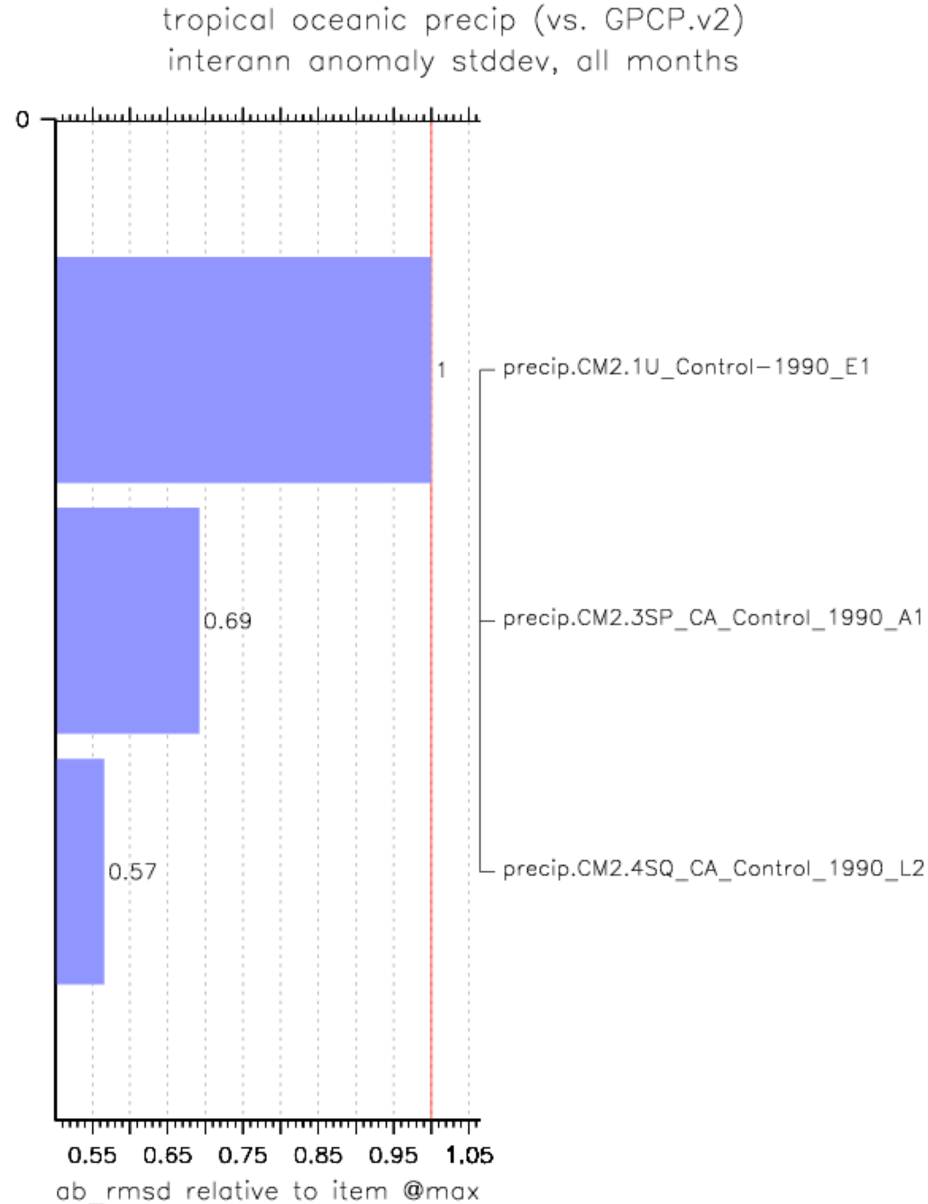

NINO3 SST from CM2.4SQ_CA_Control_1990_L2 (0001-0060)
(a) Timeseries (monthly, annual, decadal): s=1degC
ave: 25.1, 25.1, 25
std: 1.36, 0.857, 0.166
skew: 0.284, 0.433, 0.241
max: 29.1, 27.3, 25.4
min: 22, 23.4, 24.7
(b) Spectral density (s² octave⁻¹)
period (YR)
contour=0.5
(c) Mean spectra,
first/last/mid/all epochs
s² octave⁻¹
(d) Integrated variance: short < 1.4YR < long
long_int25: 2.3
long_int50: 2.7
long_int75: 3.5
short_var: 0.73
long_var: 1
wavelet σ² = 1.74 (93.8%)


NINO3 SST from NOAA ER.v3 Obs (1880-2007)
(a) Timeseries (monthly, annual, decadal): s=1degC
ave: 25.6, 25.7, 25.6
std: 1.24, 0.687, 0.229
skew: 0.0109, 0.445, 0.292
max: 29.1, 28.4, 26.1
min: 22.6, 24.1, 25.2
(b) Spectral density (s² octave⁻¹)
period (YR)
contour=0.5
(c) Mean spectra,
first/last/mid/all epochs
s² octave⁻¹
(d) Integrated variance: short < 1.4YR < long
long_int25: 2.4
long_int50: 3.5
long_int75: 5.2
short_var: 0.88
long_var: 0.58
wavelet σ² = 1.46 (95.2%)


zonal wind stress (cPa)
T > 1yr, anom stddev of all months
(a) ERA40 reanalysis (1979-2001)
ave 0.838
std 0.325
max 3.2
min 0.0998
(b) CM2.1U_Control-1990_E1 (0001-0100)
ave 1.09
std 0.503
max 2.29
min 0.107
(b)-(a)
fields interpolated to (a)x(b) grid
ave 0.255
std 0.316
max 1.33
min -2.31
corr(a,b) = 0.79
RMSD(a,b) = 0.406
zonal wind stress (cPa)
T > 1yr, anom stddev of all months
(a) ERA40 reanalysis (1979-2001)
ave 0.834
std 0.323
max 2.81
min 0.101
(b) CM2.3SP_CA_Control_1990_A1 (0001-0060)
ave 0.77
std 0.327
max 1.62
min 0.0818
(b)-(a)
fields interpolated to (a)x(b) grid
ave -0.0633
std 0.254
max 0.751
min -1.96
corr(a,b) = 0.69
RMSD(a,b) = 0.262
zonal wind stress (cPa)
T > 1yr, anom stddev of all months
(a) ERA40 reanalysis (1979-2001)
ave 0.835
std 0.324
max 3.39
min 0.131
(b) CM2.4SQ_CA_Control_1990_L2 (0001-0060)
ave 0.821
std 0.326
max 1.72
min 0.105
(b)-(a)
fields interpolated to (a)x(b) grid
ave -0.0147
std 0.232
max 0.73
min -2.6
corr(a,b) = 0.74
RMSD(a,b) = 0.233
20°N
10°N
0°
10°S
20°S
60°E
120°E
180°
120°W
60°W
0°



tropical oceanic surface fields (vs. ERA40)
interann anomaly stddev, all months
4
1
0.62
0.43
1
0.64
0.57
t_surf.CM2.1U_Control-1990_E1
t_surf.CM2.3SP_CA_Control_1990_A1
t_surf.CM2.4SQ_CA_Control_1990_L2
tau_x.CM2.1U_Control-1990_E1
tau_x.CM2.3SP_CA_Control_1990_A1
tau_x.CM2.4SQ_CA_Control_1990_L2
0.40 0.60 0.80 1.00
ab_rmsd relative to item @max



tropical oceanic precip (vs. GPCP.v2)
interann anomaly stddev, all months
0
1
0.69
0.57
precip.CM2.1U_Control-1990_E1
precip.CM2.3SP_CA_Control_1990_A1
precip.CM2.4SQ_CA_Control_1990_L2
0.55 0.65 0.75 0.85 0.95 1.05
ab_rmsd relative to item @max

Decadal

Crucial points:

• Robust predictions will require **sound theoretical understanding** of decadal-scale climate processes and phenomena.

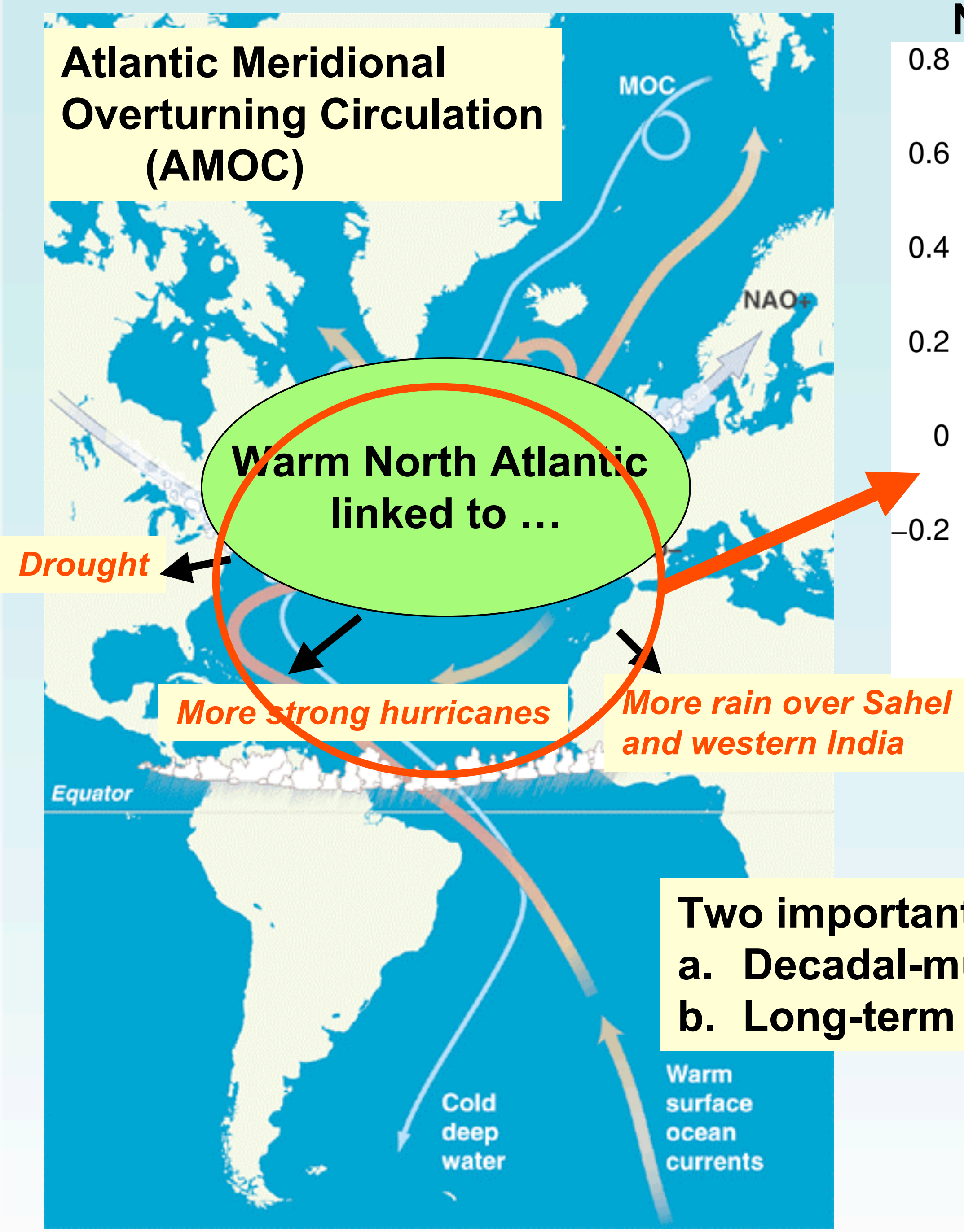
• Assessment of predictability and its climatic relevance **may have significant model dependence**, and thus may evolve over time (with implications for observing and initialization systems).

But … even if decadal fluctuations are not predictable, it is still important to understand them to better understand and interpret observed climate change.

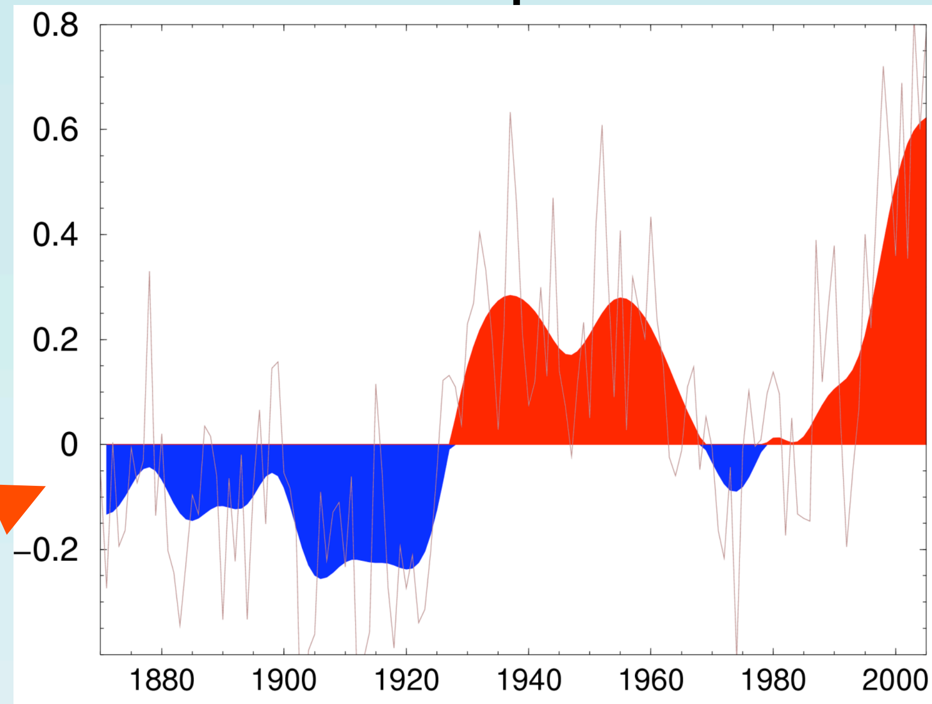
GFDL Decadal Prediction Research in support of IPCC AR5

Key goal: assess whether climate projections for the next several decades can be enhanced when the models are initialized from observed state of the climate system.

- **Use ECDA for initial conditions from “observed state”**
  - **Produce ocean reanalysis 1970-2009**
- **Use “workhorse” CM2.1 model from IPCC AR4 [2009]**
  - **Decadal hindcasts from 1980 onwards (10 member ensembles)**
  - **Decadal predictions starting from 2001 onwards (10 member ensembles)**
- **Use experimental high resolution model (if scientifically warranted) [2010]**
  - **Decadal predictions starting from 2001 onwards (10 member ensembles)**
- **Use CM3 model for IPCC AR5 [2010, tentative]**
  - **Decadal predictions starting from 2001 onwards (10 member ensemble)**

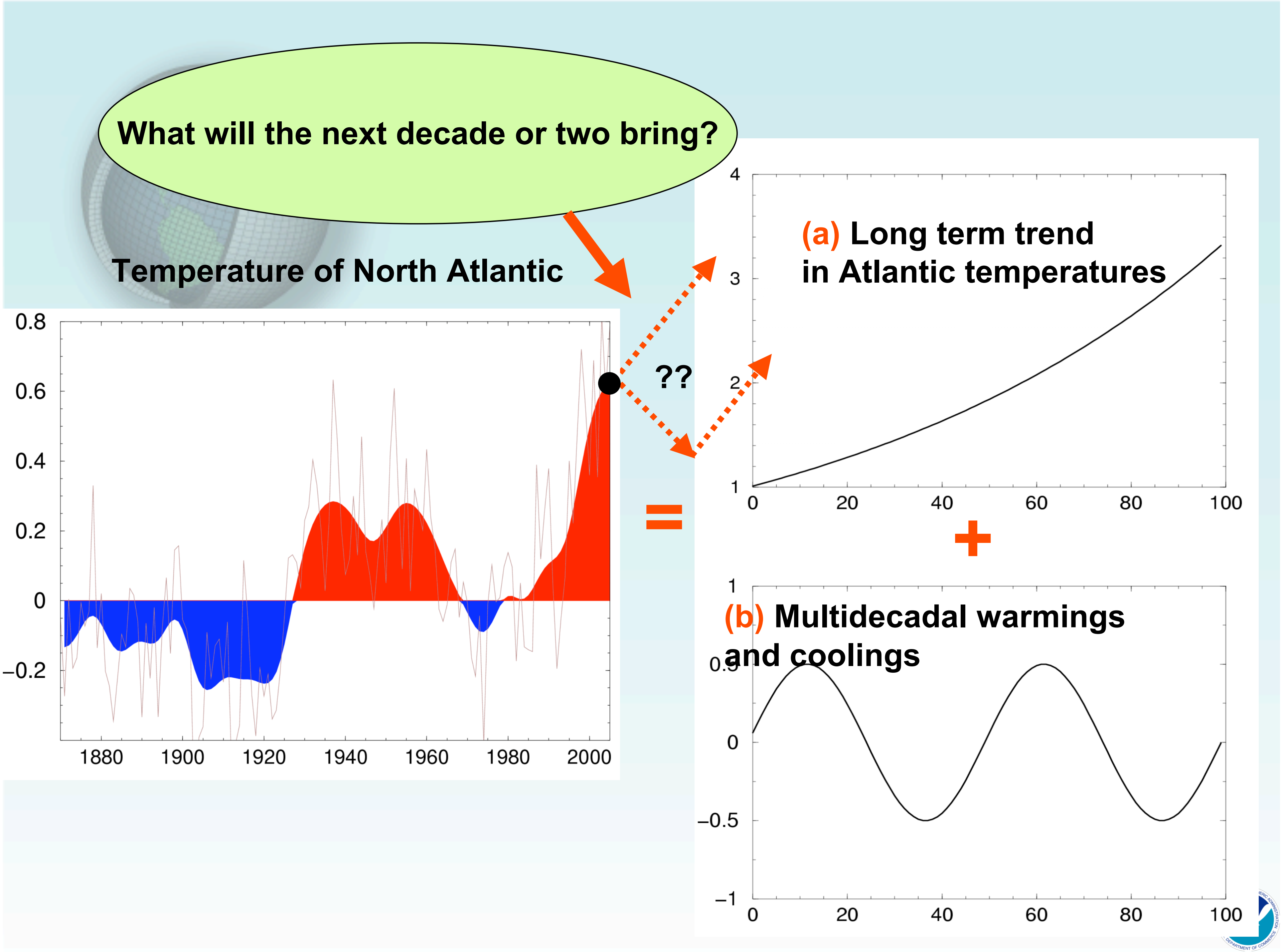


North Atlantic Temperature

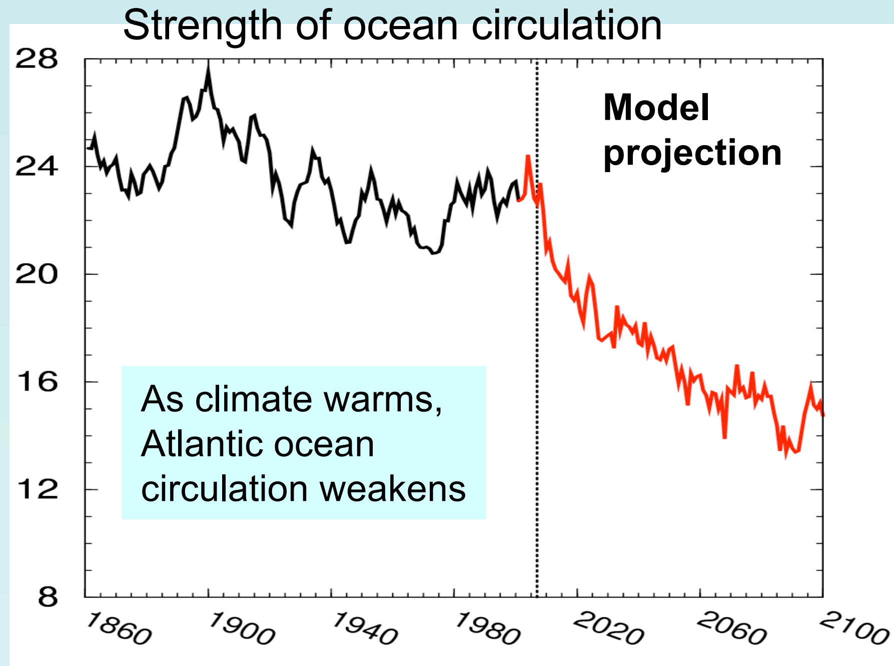


Two important aspects:

a. Decadal-multidecadal fluctuations
b. Long-term trend



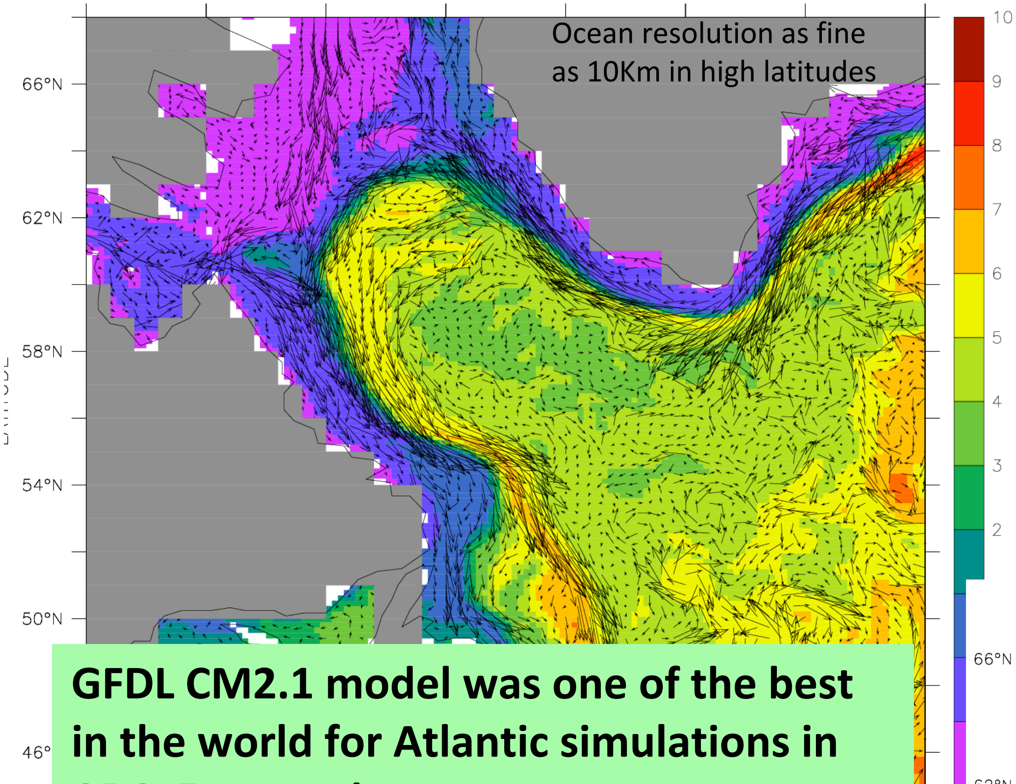
What will the next decade or two bring?
Temperature of North Atlantic
??
(a) Long term trend
in Atlantic temperatures
(b) Multidecadal warmings
and coolings
0.8
0.6
0.4
0.2
0
−0.2
1880
1900
1920
1940
1960
1980
2000
4
3
2
1
0
20
40
60
80
100
0.5
−0.5
−1



Putting the pieces together …

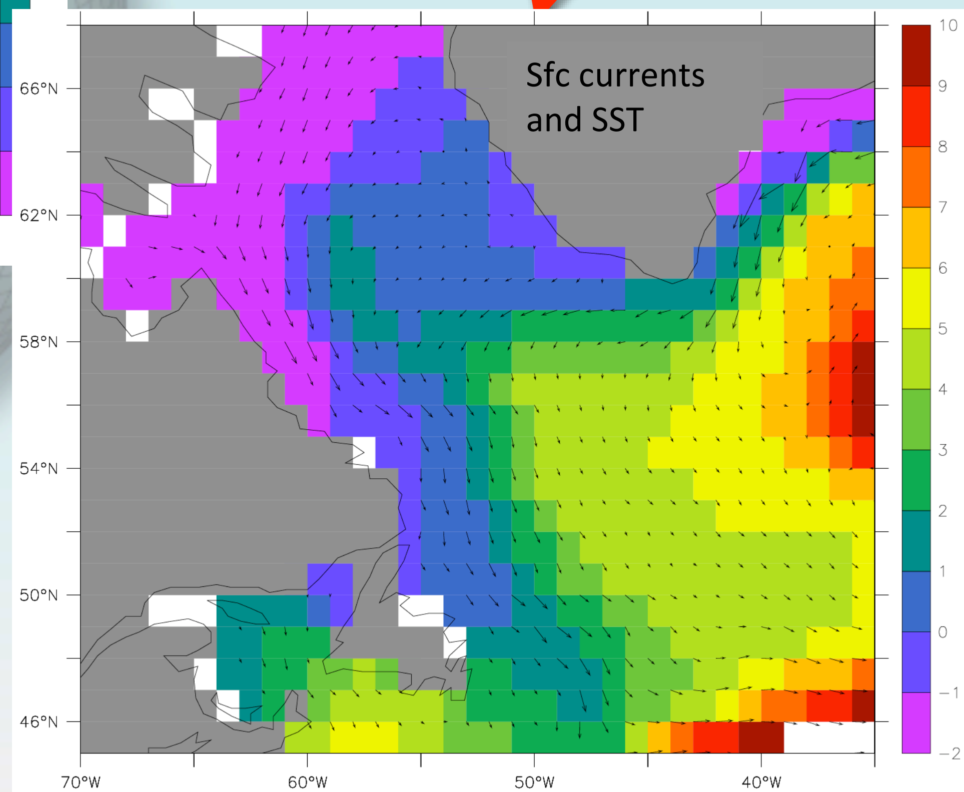
1. **Decadal-multidecadal fluctuations**
   a. **Natural variability**
   b. **Forced change**
2. **Long-term weakening trend of circulation**

GOAL: Predict decadal scale evolution of the Atlantic in response to multiple factors



GFDL CM2.4 Global Coupled Model
SST, surface currents

GFDL CM2.1 Global Coupled Model
SST, surface currents

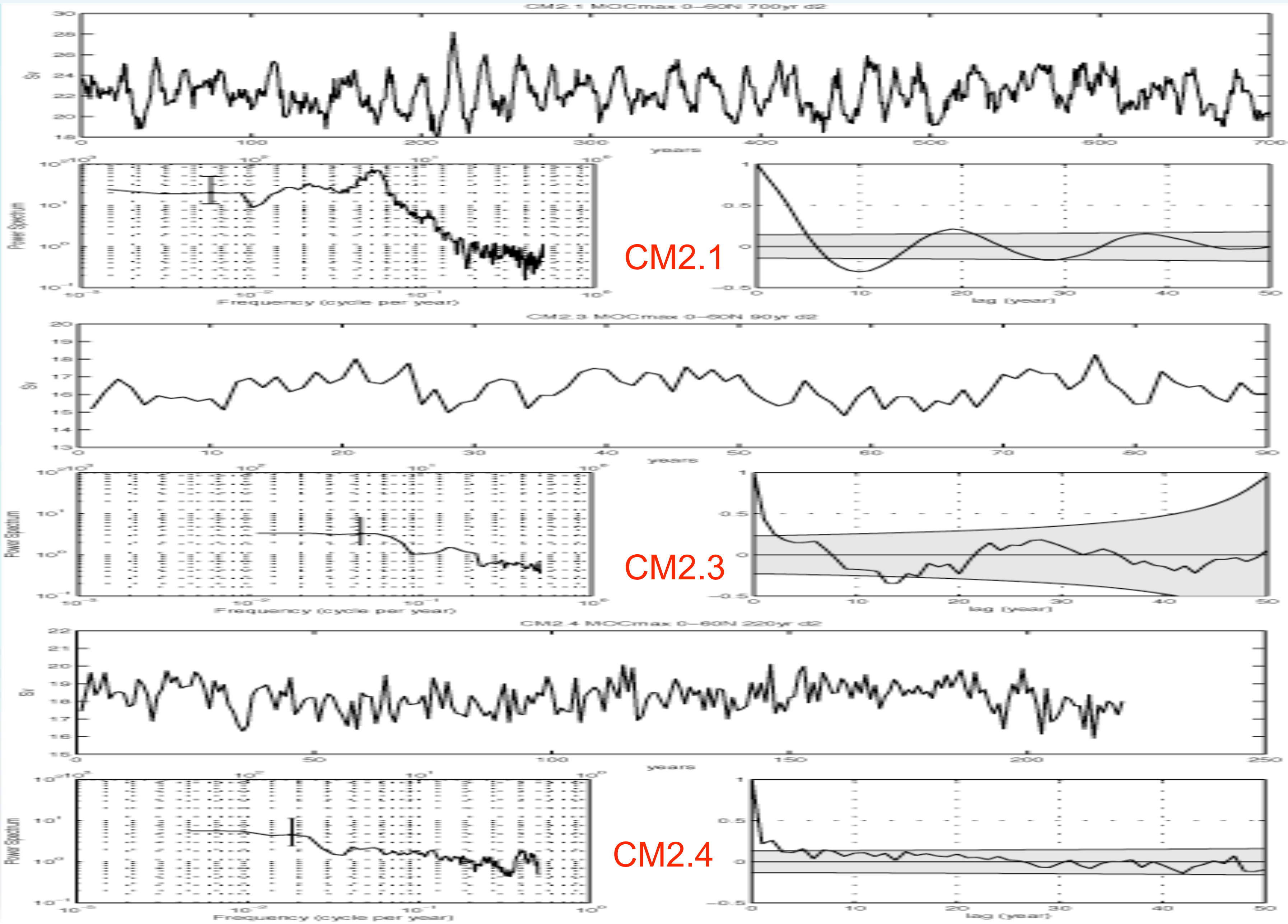


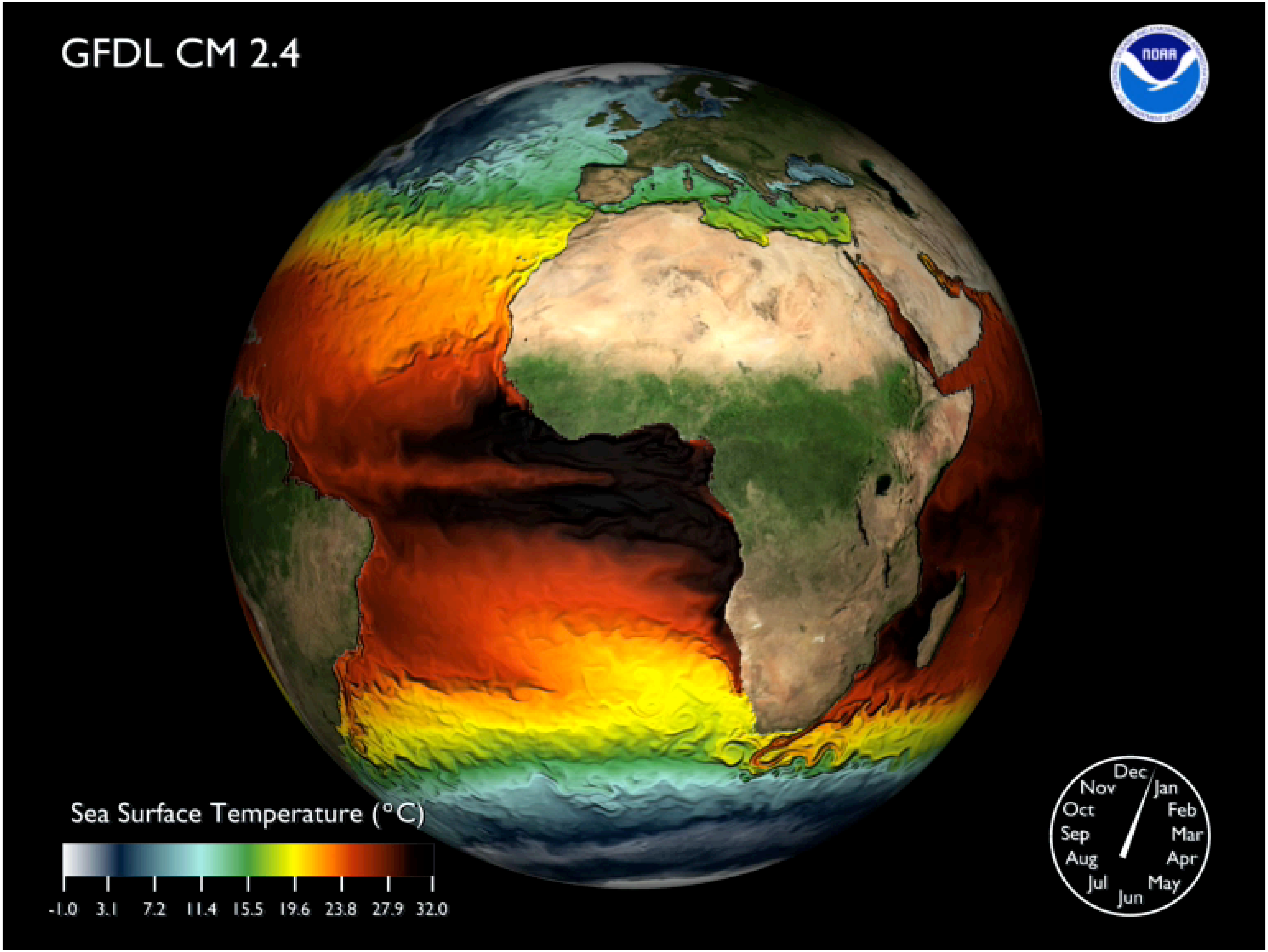
GFDL CM2.1 model was one of the best in the world for Atlantic simulations in AR4. Even so, important processes are not well resolved.

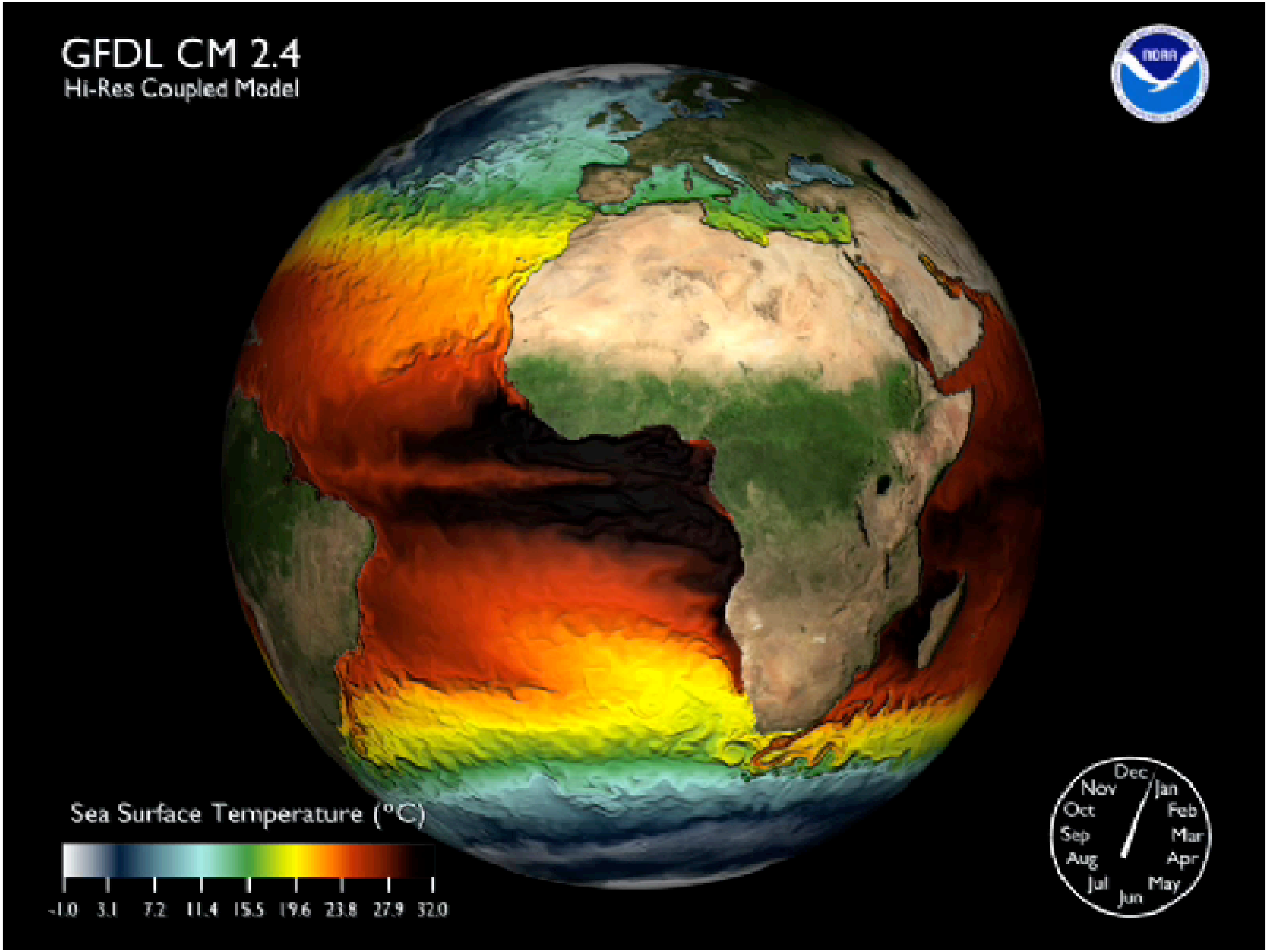
decadal variability and predictability to model resolution and physics?

Other issues:
- ocean heat uptake
- ocean circulation changes (ENSO, AMOC, Southern Ocean)

Max AMOC Variability




GFDL CM 2.4
NOAA
Sea Surface Temperature (°C)
-1.0
3.1
7.2
11.4
15.5
19.6
23.8
27.9
32.0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov


GFDL CM 2.4
Hi-Res Coupled Model
NOAA
Sea Surface Temperature (°C)
-1.0 3.1 7.2 11.4 15.5 19.6 23.8 27.9 32.0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Weather <--> Climate Connection

- **Improved regional forecast capabilities of U.S. temperatures and precipitation from a week to a season.**

- **Climate prediction capabilities for high-impact events, including droughts and major floods.**

- **Enhanced data sets and analyses to identify and interpret weather-climate connections between the tropics and mid-latitudes.**

- **Improve understanding and predictions of connections between climate variations and high impact weather phenomena (droughts, floods)**